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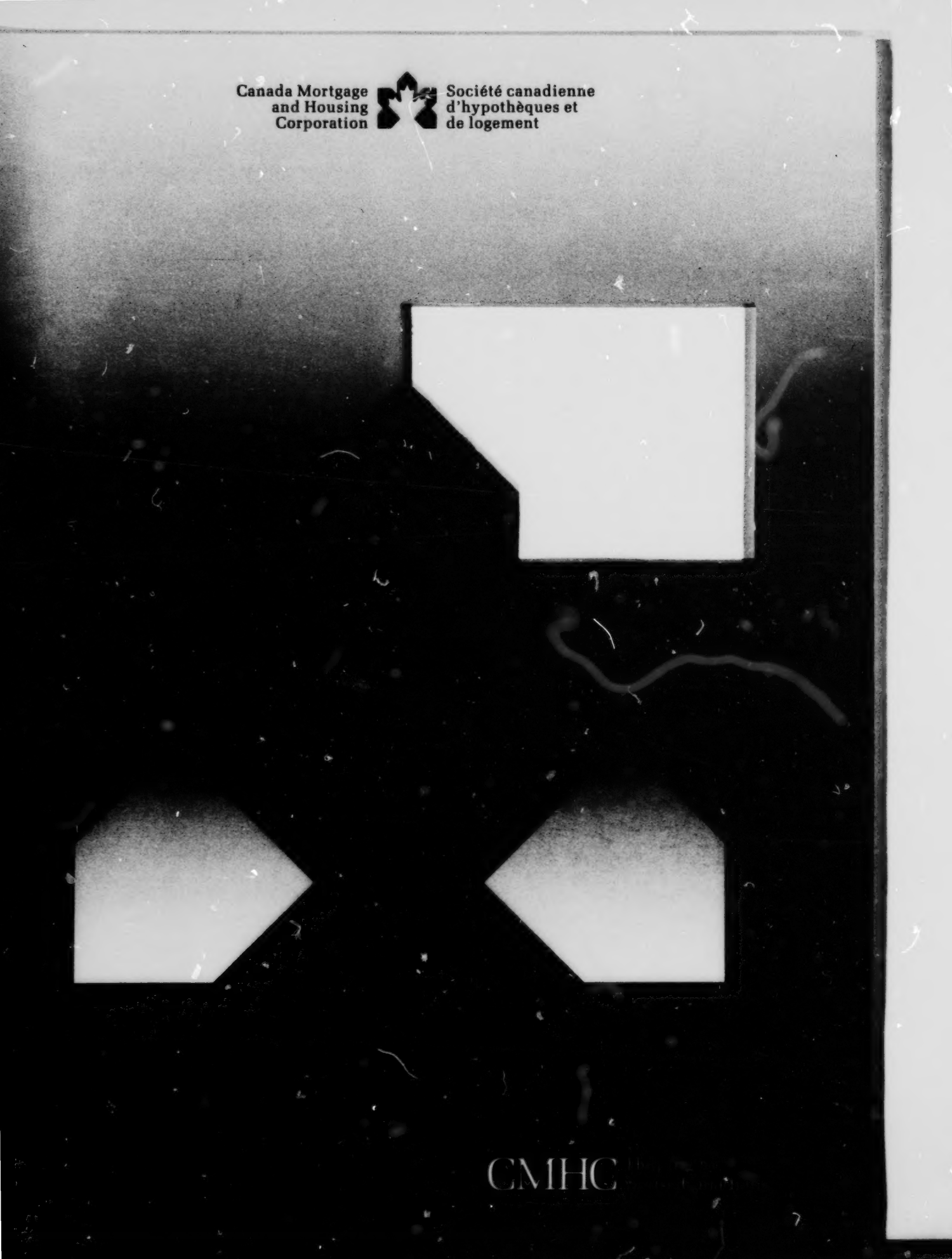

DRYING CHARACTERISTICS IN OUTER WALLS OF LOW RISE RESIDENTIAL HOUSING

FINAL REPORT

Morrison Hershfield Limited
Consulting Engineers

DRYING CHARACTERISTICS IN OUTER WALLS OF LOW RISE RESIDENTIAL HOUSING

FINAL REPORT

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EXECUTIVE SUMMARY

Introduction

Because of a strong economic need for improvement in the durability of wood frame walls in damp climates, several recent field and experimental investigations of wood frame wall performance have been undertaken that have yielded inconclusive results. Although scientists have been investigating the migration of moisture within walls for several decades, the type of hard design information needed to improve performance is not available. This demonstrated lack of understanding of the physics involved led Canada Mortgage and Housing Corporation to commission this study by Morrison Hershfield Limited with Scanada Consultants Limited.

Objective

The objective of the study was to provide a computer model of the portion of a wood frame wall, from the sheathing outwards that could be used as a tool for furthering the understanding of the physical processes involved in the wetting and drying and for the improvement of wall durability.

Scope

The study was to include a literature review, model design, model development and demonstration and an assessment of the modelling approach to wall performance investigation.

Methodology

The literature review was used to gather information to be used in development of the computer model and to confirm also that the work was not a duplication of previous research. During the preliminary design of the model, a simplified mathematical approach was used to estimate the scale of various model

parameters such as the appropriate model time step and physical resolution (i.e. distance vertically between calculation points). The model developed uses an iterative solution of three interactive models which are airflow, moisture flow and heat flow.

Results

A series of computer outputs are presented in this report that illustrate the response of the model to variations in climate and wall construction. The results show that solar radiation and wind are the two dominant driving forces for drying the wall. The results also show that the use of furring (or strapping) under siding improves the drying ability of the wall, as does the provision of an opening at the top of the wall in conjunction with furring.

Conclusions

The process of model design and development has proven to be a very efficient way of gathering, assessing and organizing what is already known about moisture migration within walls.

The model in its present form is capable of demonstrating many aspects of wall wetting and drying performance. Some of the phenomena such as night sky radiation, and rain penetration have not been modelled as first intended. These require further model development.

The use of the model now developed can also lead to a better definition of what further research is required and help to priorize that research to yield the best return on the overall investment.

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INTRODUCTION

1.1 Background

The residential construction industry is one of the major industries in our economy, employing thousands. An industry built around the supply of wood and wood based products for the home market has developed into an exporter of Canadian products that has great potential to expand. One of the hurdles facing that market expansion is public acceptance of wood construction in parts of the world (most notably Europe) where traditional masonry construction is seen as more expensive but more durable.

The lack of confidence in the durability of wood construction stems from stories of warped siding, and rotting framing. Many of these problems have been identified in our own housing stock leading to an increased overall housing cost for Canadians, and contributing to the resistance to our products abroad. It is therefore extremely important, not only for our own housing stock but also for the economy in general, to design structures that do not exhibit moisture related problems.

In recent years, houses have become tighter, insulation levels have been improved and flueless heating become more common. The incidence of moisture troubled walls has also increased. Surveys of the Canadian Housing stock have indicated a concentration of moisture problems in coastal areas. In particular there was a very high incidence of siding buckling and paint peeling noted in Newfoundland. The tighter envelopes result in higher internal relative humidities so that any remaining air leakage paths are more likely to result in local moisture condensation within the wall system as the air cools on its way out.

Vents have been proposed to act as chimneys that would lower the internal pressure in the building through the stack effect, thus preventing the outward migration of humid air. The chimney vents would also tend to improve interior air quality due to the increased internal air exchange rate. However, vents cause significant energy loss, which defeats the original purpose of building a tight house. To reclaim the heat from the vented air, heat exchangers can be used, but there are installation and equipment costs to be borne. These factors illustrate the inter-related and sometimes conflicting requirements of avoiding moisture problems, conserving energy, maintaining good internal air quality and minimizing housing costs.

The problem is that the performance of a building envelope, unlike that of an electronic component is not entirely deterministic. The envelope is constructed of many materials and components that, because of their low cost, provide good value. However, due to the nature of many of these materials (i.e. wood, fibre or particles) their performance thermally and hygrothermally varies over what, to scientists in other fields, would be considered an astonishing range. An example is the vapour diffusion resistance of building paper that may vary over at least an order of magnitude. Couple these wide ranging material properties with the variability of workmanship, construction type, moisture and thermal loading due to occupancy and the climatic variations from maritime to arctic conditions and the problem facing building scientists starts to come into focus.

The moisture transfer performance of construction systems has received much attention in recent years but no one project or procedure, reviewed during the literature survey, addressed all of the processes at work in a supposedly simple wall system.

Past research on moisture problems has focused mainly on the question of how moisture moves from inside the house, through the wall system and at what point within the wall system it condenses. There are many simple steady state theoretical models of this process, however, they do not account for other factors such as air leakage variations in the weather, solar incidence, rain or mist penetration. The question of whether moisture damage will actually occur depends on all of these factors.

Because of a demonstrated lack of understanding of the problem both in the construction industry and in the scientific community, the current research project was commissioned. Its aim was to gain a better understanding of moisture transfer in residential walls, primarily by developing a computer model.

This report is an assessment of the model's performance as currently developed. Its flexibility is demonstrated with worked examples using real weather data. Variations in input parameters were used to demonstrate the model's response rather than immitate common construction practices.

1.2 Objective

The primary objective of the study was to provide a computer model of the portion of a wood frame wall, from the sheathing outwards, that could be used as a tool for furthering the understanding of the physical processes involved in the wetting and drying and for the improvement of wall durability.

A second objective is to provide an assessment of the model designed to illustate model performance as developed to date and delineate required further research. As such, the results must not be construed as final wall performance information.

1.3 Scope

As part of the scope of the overall research program, this particular research project's goal was the development of the basic computer model, relying on past research in forming the individual moisture movement models within the larger system framework. It was recognized that lack of complete characteristics of individual processes in some instances or lack of material characteristics in others would reduce the accuracy of the model, but it was felt that a worthwhile first step would be the development of a framework into which information could be inserted when it becomes available.

In order to provide the flexibility required of such a model where individual elements may not be finalized until later, a matrix of physical properties to be modelled was developed. This matrix is presented in four groupings, moisture transport, moisture storage, heat transport and heat storage in Table 1. This matrix shows the properties that were considered important to the model and would be included either during this project or in subsequent projects.

In performing the background research for the model development, a considerable amount of literature was reviewed. This has been formed into a bibliography and is included as Appendix A to this report.

2. MODEL DESCRIPTION

2.1 General

The functions reviewed in the three dimensional matrix, shown as Tables 1-1 to 1-4, contain aspects of physics related to air

movement. One of the major objectives of this work is to try and determine the rate of air flow or air change in a strapped cavity and see how this flow affects the drying of the wall. Coupling this air flow with heat flow and moisture flow became quite important in the modelling.

In the interests of economy, the basic heat, moisture and air movement mechanisms were analyzed at the beginning of the project to determine if the model could be reduced from a general three dimensional model to something more compact. It was determined that a two dimensional section through the wall could be modelled that would illustrate all the necessary moisture transfer properties necessary. Conditions could be varied in such a model to represent any vertical section of a wall.

The basic reasoning that allowed this simplification was that a wall is essentially a layered system where lateral temperature, moisture and pressure gradients are low compared to equivalent gradients through the wall. The only area where this does not work well is air flow. By handling the air circulation within the wall as a lateral flow model in conjunction with a series of heat sources and sinks, this limitation was overcome.

The model was further simplified with, what we consider, little loss in generality by dividing the two dimensional wall section into a vertical stack of one dimensional horizontal heat and moisture flow wall model elements joined by a one dimensional vertical airflow model. Figures 1 and 2 illustrate these arrangements. This physical arrangement within the wall is used with two scalar field models which have temperature and moisture content and the vector field model of air velocity. The word element in this context refers to the one-dimensional composite moisture heat and air flow model in the vertical stack of models. Each one-

dimensional element is modelled by a series of layers across the wall consisting of the properties for the various building materials within the wall. A location within the wall can therefore be uniquely specified by its element number (vertical direction) and its layer number (horizontal direction).

The moisture, temperature and air velocity field models are coupled since each field is dependent upon the other two. Figure 2 shows the basic interrelationship of the three field models.

TABLE 1-1
MOISTURE TRANSPORT

WALL COMPONENT	FORM OF MOISTURE	LIQUID		HYGROSCOPIC MOISTURE	VAPOUR	
	TRANSPORT MECHANISM	GRAVITY DRAINAGE	AIR(WIND) PRESSURE	CAPILLARITY DIFFUSION, SURFACE DIFFUSION	DIFFUSION	CONVECTION
	LOCATION					
Siding	Outer Face	W, M	W, M	W, M, A	W, M	W, M
	Within				W, M, A	W, M, A
	Around	W, M	W, M		W, M, A	W, M, A
	Inner Face	W, M	W, M, A			
Outer Airspace	Within				W, M, A	W, M, A
	Across		W, M, A			
Building Paper	Outer Face	W, M	W, M, A	W, M, A	W, M, A	W, M, A
	Within					W, M, A
	Around				W, M	W
	Inner Face	W, M				
Inner Airspace	Within				W, M	W
Sheathing	Outer Face	W, M		W, M, A	W, M, A	W, M, A
	Within					

Note: W - phenomenon is likely to occur in a wall
M - the model is planned
A - actually modelled at completion of study

TABLE 1-2
MOISTURE STORAGE

WALL COMPONENT	FORM OF MOISTURE / STORAGE MECHANISM / STORAGE LOCATION	SOLID: SURFACE ADHESION	LIQUID: SURFACE ADHESION	VAPOUR: VAPOUR IN AIR	SORBED: ABSORBED, ADSORBED, VAPOUR IN MATERIAL
Siding	Outer Face	W, M, A	W, M, A		
	Within				W, M, A
	Between Boards	W, M	W, M, A		
	Inner Face	W, M, A	W, M, A		
Outer Airspace	Within			W, M, A	
Building Paper	Outer Face	W, M, A	W, M, A		
	Within				W, M
	Inner Face	W, M	W, M		
Inner Airspace	Within			W, M	
Sheathing	Outer Face	W, M, A	W, M, A		
	Within				W, M, A

Note: W - phenomenon is likely to occur in a wall
M - the model as planned
A - actually modelled at completion of study

TABLE 1-3
HEAT TRANSPORT

WALL COMPONENT	TRANSPORT MECHANISM / LOCATION	CONDUCTION	CONVECTION[1]	RADIATION
Siding	Outer Face	W, M, A	W, M, A	W, M
	Within	W, M, A	W	W
	Around	W, M, A	W, M, A	
	Inner Face	W, M, A	W, M, A	W, M, A
Outer Airspace	Within	W, M, A	W, M, A	
	Across			W, M, A
Building Paper	Outer Face	W, M, A	W, M, A	W, M, A
	Within	W, M, A	W	W
	Around	W	W	W
	Inner Face	W, M, A	W	W, M, A
Inner Airspace	Within	W, M	W	
	Across			W, M
Sheathing	Outer Face	W, M, A	W, M, A	W, M, A
	Within	W, M, A	W	W
	Inner Face	W, M, A	W, M	W

Note: W - phenomenon is likely to occur in a wall
M - the model as planned
A - actually modelled at completion of study

TABLE 1-4
HEAT STORAGE

WALL COMPONENT	STORAGE LOCATION	STORAGE MECHANISM: DRY MATERIAL	DRY AIR	WATER VAPOUR	LIQUID WATER (LATENT)	SORPED MOISTURE (LATENT)	ICE (LATENT)
Siding	Outer Face				W		W
	Within	W, M, A				W, M, A	
	Inner Face				W, M, A		W, M, A
Outer Airspace	Within		W	W			
Building Paper	Outer Face				W, M, A		W, M, A
	Within	W				W	
	Inner Face				W, M, A		W, M, A
Inner Airspace	Within		W	W			
Sheathing	Outer Face				W, M, A		W, M, A
	Within	W, M, A				W, M, A	
	Inner Face				W		W

Note: W - phenomenon is likely to occur in a wall
M - the model as planned
A - actually modelled at completion of study

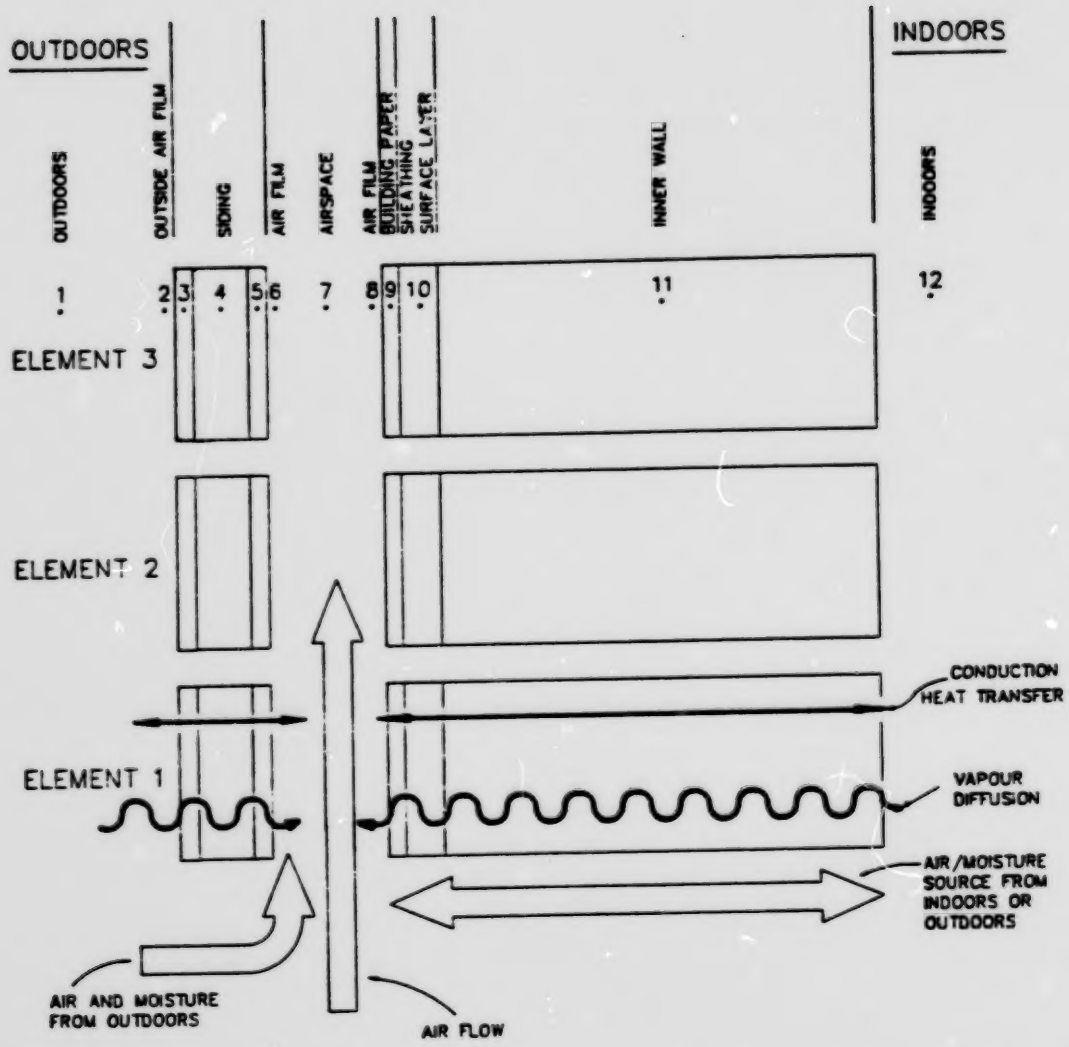


FIGURE 1
MODEL SCHEMATIC

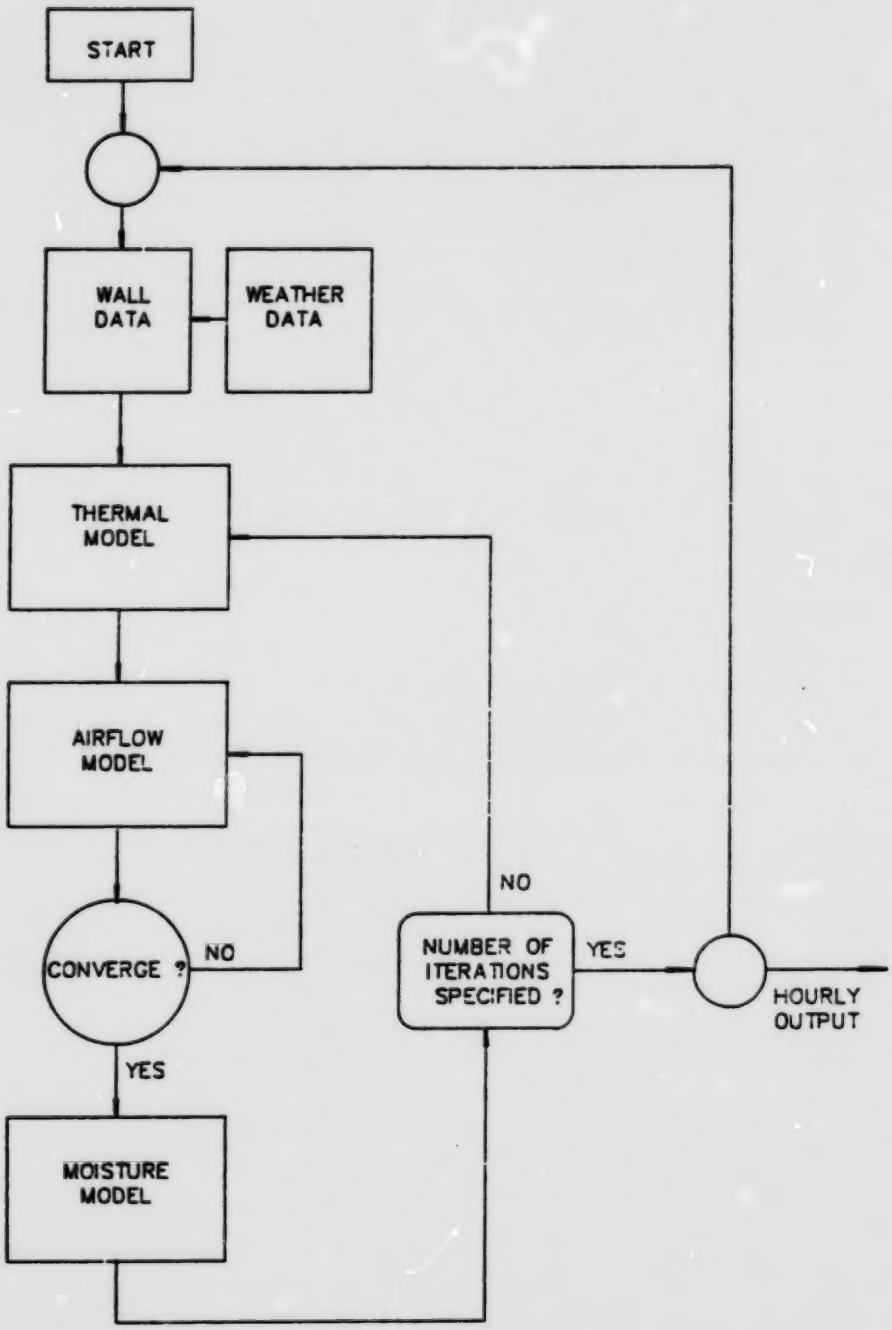


FIGURE 2
MODEL FLOW CHART

2.2 Modelling Approach

The main emphasis of the modelling approach has been on the investigation of the interactions or links between the various layers of a wall and between the various phenomena that are occurring simultaneously in the wall as outlined in Tables 1-1 to 1-4. The simplest forms were chosen of the various algorithms available. By studying the resulting interactions and by sensitivity analysis, we determined how to more properly model the system and determined also where a better understanding of material properties was needed.

The algorithms used can be classified as basic "textbook science". The complexity of the modelled system thus arises not from the algorithms but from:

- The interactions between the various phenomena at work (heat transfer, moisture transfer and air movement)
- the vast differences in properties of various materials
- the resulting vast differences in the time frames in which the phenomena operate
- the phase changes of water in the wall

These complexities are the focus of the modelling work.

2.3 Model Space and Time Relationships

Since the intent is to model wall details with sufficient accuracy to determine specific moisture content time histories, it is important to investigate the wall performance on a preliminary

basis to ensure that the appropriate physical lengths and time increments are used. A time increment of one hour would be convenient, since there is a great deal of computerized hourly meteorological data.

The moisture content of the wall components is the quantity that we need to describe at any point in time. To determine this moisture content accurately, we must describe the response of the system to any input. One component of the model is the time step chosen. The time step used must be a small fraction of the response time of the system. The time step chosen in the model must therefore be much shorter than the known response time of the moisture content of building products in relation to a change in surrounding ambient conditions.

In systems governed by first order differential equations, the response time can be described in terms of a time constant. In such a system, the response of a property to a step change in conditions can be written in the form:

$$J = A\ (1 - e^{-t/\tau})$$

where

J is the parameter of interest
A is the amplitude of the step change in an influencing condition
t is time
τ is the time constant

Appendix B is an analysis which examines the typical time constants that are likely to govern the moisture content time history.

From this analysis, one can see that typical time constants can be a few seconds for airspaces, but are generally hours, days or months for porous building materials. These time constants indicate that the 1 hour time step we have selected shall be adequate to ensure that the model will produce useful information.

In considering the physical step size necessary to adequately characterize the moisture content distribution within the wall, we consider the airflow model in the airspace behind the siding as well as the typical siding geometry (Figure 2). From Appendix B a characteristic length can be determined for a set of conditions that parallels the time constant in the time domain. The moisture content characteristic length of the airspace can be estimated as the product of the moisture content time constant and the velocity of air moving up the airspace. It is shown in Appendix B that the characteristic length for moisture content may range from one millimeter to over 2 meters. To provide a model with a vertical resolution of 1mm would be impractical since the model is to run hourly for at least a period of a year. The airspace velocity behind the siding is governed by the pressure differentials at the horizontal gaps of the joints between siding boards. It was decided accordingly that one board width would be the minimum physical step size (i.e. about 200mm). Physical resolution on a smaller scale, although interesting, is not of critical concern to the drying performance of the wall.

The model has been designed therefore to use hourly time steps for which hourly weather data is available, and a vertical resolution of approximately 200mm.

2.4 The Heat Transfer Model

To accomodate any number of heat sources and sinks in the wall

(e.g. latent heat gains or losses at any layer within an element), the transport of heat in the air space, a series of simultaneous equations were set up. These model the heat balance through all layers from inside to outside while accounting for latent heat and sensible heat storage effects at every layer within the element. Thus, quantities of latent heat calculated in the moisture flow model can be treated as a heat source/sink in the thermal model. The vertical transport of heat in the airspace is treated by the one dimensional heat transfer model as an air change heat loss or gain at the air space layer (see Figure 1).

The general formulation of the energy balance of each layer is an expression of continuity of energy:

Net heat transfer through the layer by conduction	=	heat gain + heat losses by other means

Among the "heat gains and losses" treated are:

- radiant heat (e.g. for the siding or exterior air film)
- latent heat (from evaporation and condensation melting & freezing of water)
- sensible heat (stored in the layer by a change in temperature from the previous hour)
- air change heat transport in the air space

These heat gains and losses are calculated for each hour, for each element. There is one equation for each layer of each element. The equations, when written out, form a "banded" matrix of heat loss factors multiplied by layer temperatures. These equal the net heat generation or loss in each layer. The generalized

expression is solved by a standard matrix solution of simultaneous equations.

2.5 Airflow Model

The mass flows and pressure drops are calculated sequentially, using the principle of Continuity of Mass and a generalized form of the friction pressure drop term. The continuity of mass is of the first order, and the pressure drop terms are represented as polynomials with exponents n = 0.5 and n = 1. The weighting of each of the two terms is determined by the Reynolds number of the flow and the surface characteristics of the flow path.

The weighting has been arbitrarily assigned, based on our own judgement of the surface conditions but is subject to change when further experiments determine the actual flow conditions.

2.6 Moisture Transfer Model

To make the system interactions between thermal, moisture and air flow models manageable, we have assumed that the hourly time step must be preserved in the moisture transport model. Relative to the size of an hour interval, the moisture content in the wall layers can assumed to be constant over that hour. The moisture properties of these layers can thus be used as fixed boundary conditions to the flow calculations applied to adjacent air layers over one hour.

Again relative to the hour calculation interval, those elements involving air (e.g. the moving air space) can be assumed to have reached steady-state conditions with their boundaries very early within the hour. We believe the modelling of the drying problem is thus reduced to calculating equilibrium hourly moisture

conditions of air relative to its boundaries given a set of temperatures and boundary conditions for the hour. The total rate of moisture taken/deposited in the boundary (water film, ice, wood) is the quantity of water that flows as a result of those equilibrium conditions.

The moisture flow model involves:

1) Establishing the psychrometric conditions at the surface of the layers containing water.

2) Calculating the equilibrium properties of the air layers within each element (vapour pressure, RH, absolute humidity) as they respond to the adjacent layers containing water and to the temperature field of that hour.

3) Calculating the rates of moisture flow that result from these equilibrium conditions for the air layers.

4) Integrating these moisture flow quantities over the hour and updating the moisture contents of the boundaries (water film, ice, wood) for the next hour of calculation.

5) Repeating these calculations over a full year, keeping track of drying/wetting rates of the wood and water layers and integrating these to obtain the moisture content histories of the layers within each element over the full year.

The moisture transport equations of interest are the ones applied to Element 7 (Figure 1) (the moving air element) because the hourly equilibrium moisture content of this air is unknown. We have applied the principle of continuity of mass of the vapour to

calculate the equilibrium absolute humidity of the moving air element for each hour.

The transport of vapour from the boundaries to the air space is treated as a pure vapour pressure equation. The absolute mass of the water is substituted for the vapour pressure using the perfect gas law.

3. RESULTS

3.1 Types of Results

The model in its present form has been used to generate two different forms of results for the two different purposes included in the scope of this study. Several runs have been made using steady state inputs to generate distributions within the wall for fixed conditions. These runs illustrate the basic performance of the wall to give an understanding of wall behaviour in general.

The second set of runs gives hourly time histories of various parameters for an extended period, using hourly weather data. These time histories demonstrate the long term response of the wall to real weather given an initial high moisture content of the wall materials. The results illustrate the use of the model as a design tool to determine the reliability of given wall constructions.

The large number of parameters involved, and the interrelationship of the phenomena at work, make analysis of results complicated. The example results given in the figures that follow have been chosen to illustrate various aspects of the models performance. With careful scrutiny, a great deal more information can be extracted from the example than is described here.

3.2 Distributions Within the Wall

A series of computer runs was made with fixed weather inputs to determine temperature, drying rate, relative humidity and velocity profiles within the wall. These runs act as "snapshots" of the wall under controlled conditions and give an understanding of the interdependence of the various parameters such as gap width, airspace thickness, wind speed, etc.

The running of the program requires a "wall" file which describes the wall in terms of materials, thicknesses, opening dimensions etc. Table 2 is an example of the wall file. The first line of Table 2 is simply a title that gives a brief description of the wall. The reference to Halifax south wall indicates that the preprocessed hourly weather data is for a south facing wall located in Halifax. The appropriate data file is specified within the table. A prompt in the program asks if weather data is to be used. If not, it asks for a set of fixed weather conditions, and ignores the weather data file, named in the table.

The material properties are specified by numbers from a materials database given in Appendix C. Those properties are handbook values subject to modification if desired.

The conditions shown in Table 2 have been chosen as the benchmark wall.

Changes from the benchmark wall, that have been made for each run are shown on each of Figures 3 to 28. Any parameter not mentioned on a figure is the same as that given in Table 2. Note that the wall height has been set to 6m on the base wall, making each of the 9 elements 67 cm tall. The effect of a change in wall height is also investigated by comparing the 6m wall results with a 2m

wall. These heights were chosen more as a demonstration of performance variations with height than as a reflection of common construction. Shown on the figures are the weather conditions used.

TABLE 2
WALL CONSTRUCTION FILE

HALIFAX SOUTH WALL: 20mm AIR SPACE, 20mm OPENING AT THE TOP, 3 ITERATIONS

NUMBER OF ELEMENTS UP THE WALL (NV) AND LAYERS THROUGH THE WALL (NE) 9, 12

SELECTION OF MATERIALS FOR EACH LAYER (SEE PROPERTIES DATABASE FOR #) 1, 15, 16, 16, 16, 4, 5, 4, 6, 7, 8, 9

THICKNESS OF EACH LAYER (m)
1,0.002, 0.005, 0.005, 0.005, 0.002, 0.02, 0.002, 0.0005, 0.005, 0.095,1

WALL HEIGHT (m), WALL LENGTH (m)
6, 9

SIDING GAP CHARACTERISTICS: WIDTH (m), FLOW PATH LENGTH (m), FLOW EXPONENT 0.001, 0.01, 0.9

TOP OPENING CHARACTERISTICS: WIDTH (m), FLOW PATH LENGTH (m), FLOW EXPONENT 0.020, 0.02, 0.8

AIR SPACE CHARACTERISTICS: NUMBER OF THE LAYER, FLOW EXPONENT 7, 0.8

WIND PRESSURE COEFFICIENTS FROM BOTTOM TO TOP (9 elements + UPPERMOST OPENING) 0.1, 0.2, 0.3, 0.4, 0.5, 0.5, 0.4, 0.3, 0.2, 0.1

WALL ORIENTATION (DEGREES FROM NORTH): N:360, E:90, S:180, W:270
180

NAME OF THE WEATHER DATA FILE (INCLUDE THE DRIVE SPEC: e.g. A:DWEATH.SOU) A:HAL.SOU

MOISTURE SOURCE STRENGTH IN kg/hr, & LOCATION: LAYER # & ELEMENT NUMBER 0, 7, 3

SIMULATION START AND END (DAY OF YEAR) 1,365

NUMBER OF ITERATIONS BETWEEN THE 3 MAJOR SUB MODELS 3

3.2.1 Discussion of Results

Figures 3 to 7 show vertical distributions of drying rate at layer 10 (sheathing), airspace relative humidity, airspace temperature, air velocity through the siding gaps, and airspace air velocity for the wall conditions described in Table 2. This wall condition includes a 20 mm airspace, 20 mm opening at the top of the wall and 1 mm gaps between siding boards.

The temperature profiles in Figure 5 exhibit the expected patterns with the solar input causing a marked increase in airspace temperature with each 67cm increment up the wall. The temperature in the airspace appears to be well correlated with the gap flow velocity for the windy case. This appears reasonable since the air entering through the gaps is lower in temperature than the airspace. One might expect this trend to carry over to the drying rate. However on comparison of Figure 3 with Figures 6 and 7, it can be seen that drying rate more closely correlates to airspace velocity (Figure 7).

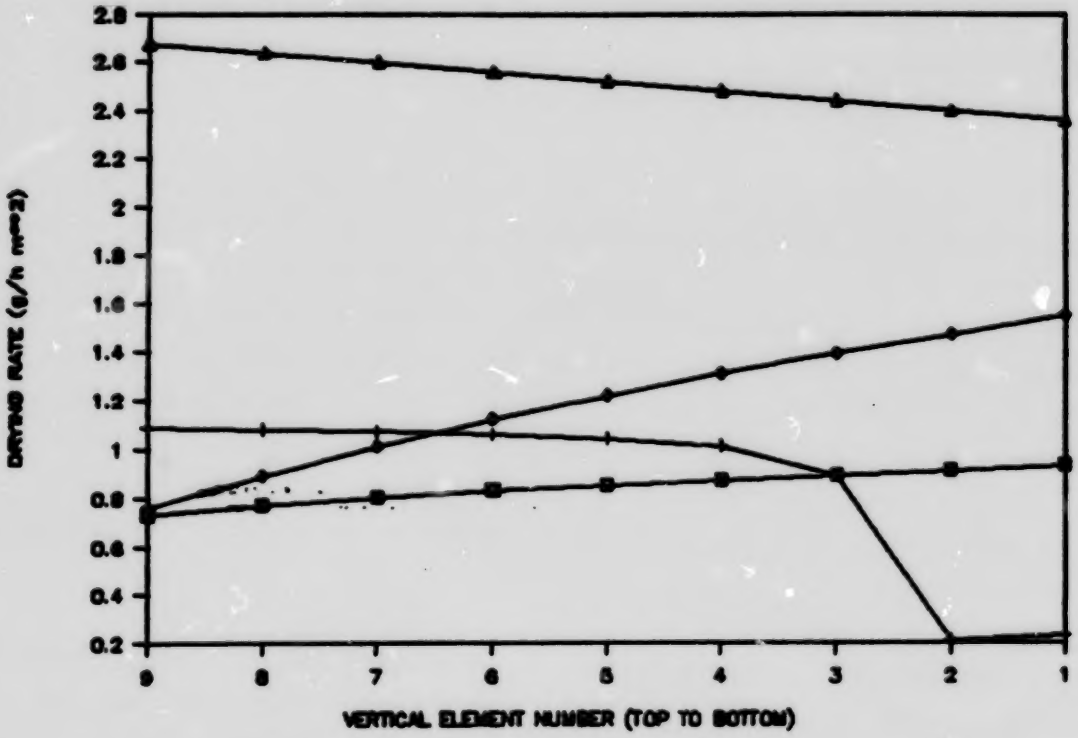
Comparison of Figures 6 and 7, the gap and airspace velocity profiles, shows that the airspace velocity is the integral of the gap velocity. The airspace velocity shows the effect of the large top opening, since the velocity is all upwards showing no neutral plane or flow reversal.

The gap velocity for the 20 kph wind case (Figure 6) exhibits a profile similar in shape to the profile of pressure coefficients used as input, with the addition of a positive skew towards the top due to the large opening.

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



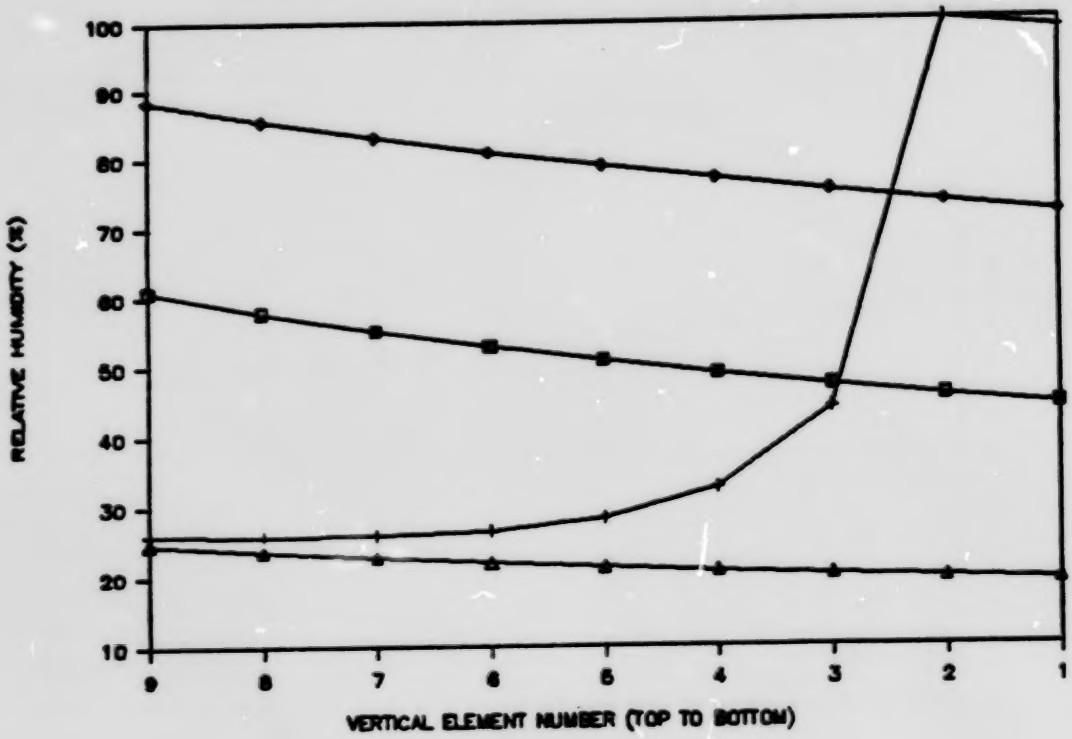
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◆	0	10	0
▲	0	-10	1000

FIGURE 3
DRYING RATE PROFILES
AT LAYER 10

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



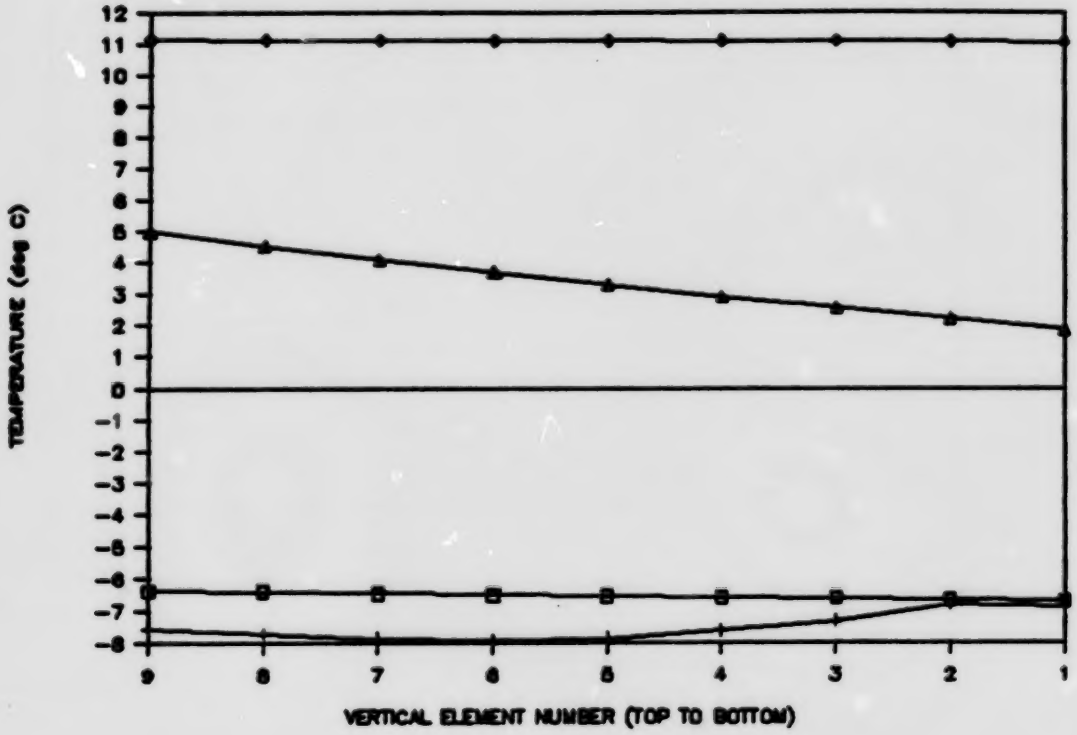
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
[	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 4
RELATIVE HUMIDITY PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



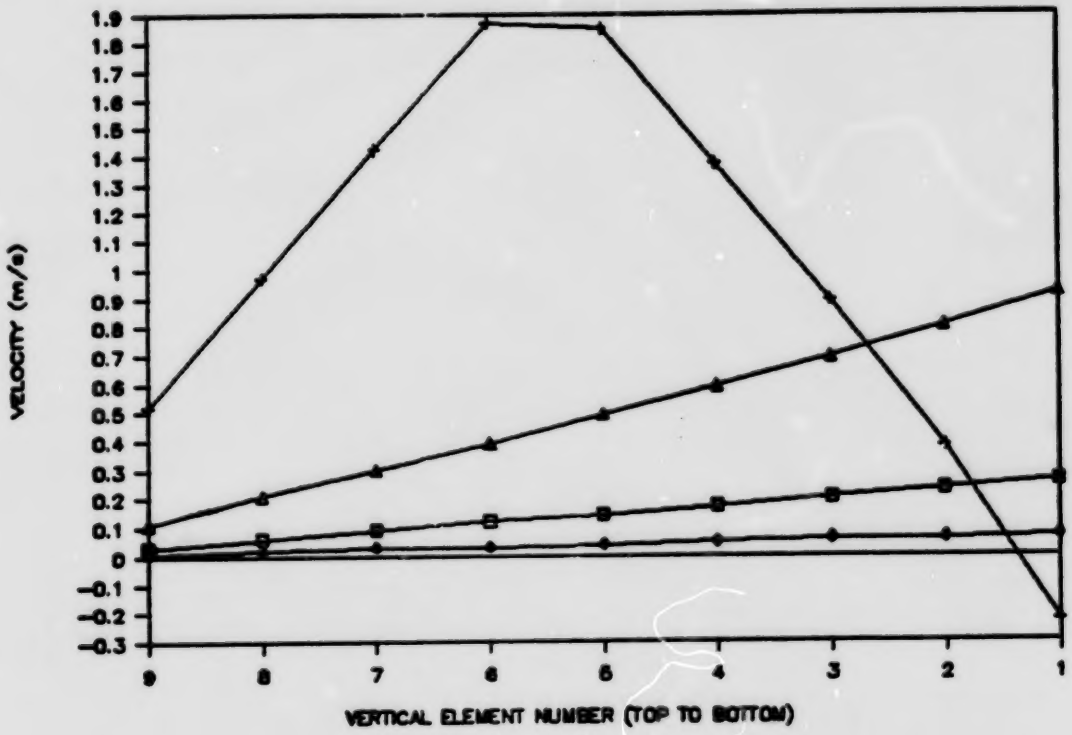
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 5
TEMPERATURE PROFILES IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



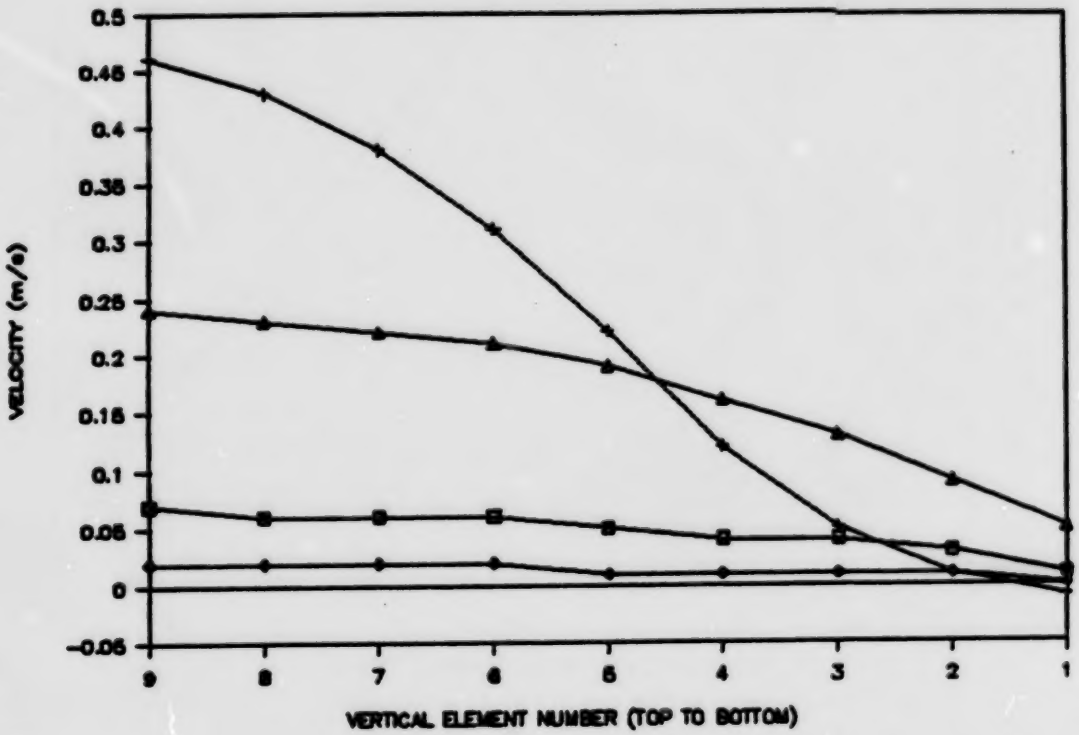
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 6
VELOCITY PROFILES
IN THE GAP

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 7
VELOCITY PROFILES
IN THE AIRSPACE

Figures 8 to 22 show the same results for three other wall conditions. One interesting point can be seen by comparing weather conditions 1 (-10°C) and 3 (+ 10°C) on Figures 13 to 17. Although at the higher temperature there is less stack effect and therefore a lower airspace velocity resulting in higher relative humidity, the actual drying rate is still higher due to the increased vapour pressure differences involved.

The effect of wind on drying rate at first glance seems confusing. This is due in large part to the model structure. The gaps are at the bottom of each element as they are on real siding. At a point of flow reversal such as element 5, the air entering through the gap is split and travels up to element 5 and down to element 4. This splits the drying effect of the air entering gap 5, creating a poor drying condition in elements 4 and 5. However, once the flow direction is fixed (i.e. elements 6 and 7), the drying conditions rapidly improve.

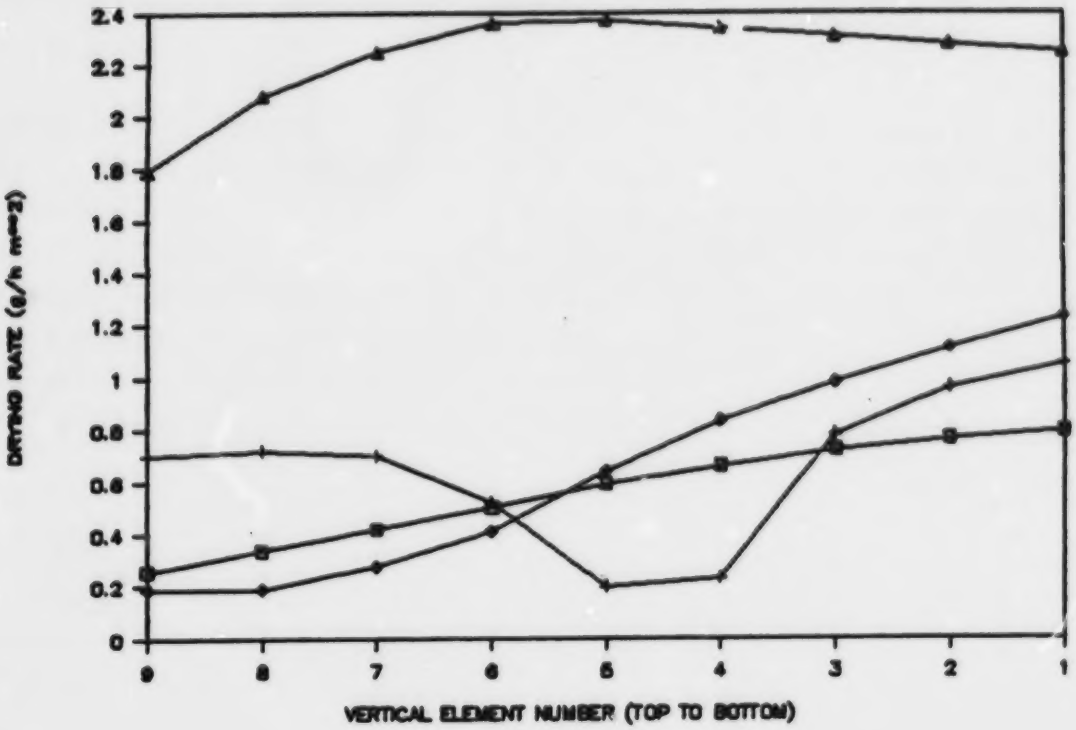
The effect of closing off the top opening can be seen in Figure 12. A neutral plane has been created with flow inwards at the bottom and outwards at the top. The opening up of the siding gaps to 3mm creates a set of conditions somewhere between the open and closed top cases with 1mm gap width.

Figures 3 to 22 are grouped to make comparison of the effects of different climatic conditions convenient. For example, in most cases, solar incidence and wind are the main drying mechanisms. In Figure 13 it can be seen, however, that with the much more open siding structure, wind actually inhibits drying partly due to the flow stagnation zones, and partly due to the cooling of the airspace.

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



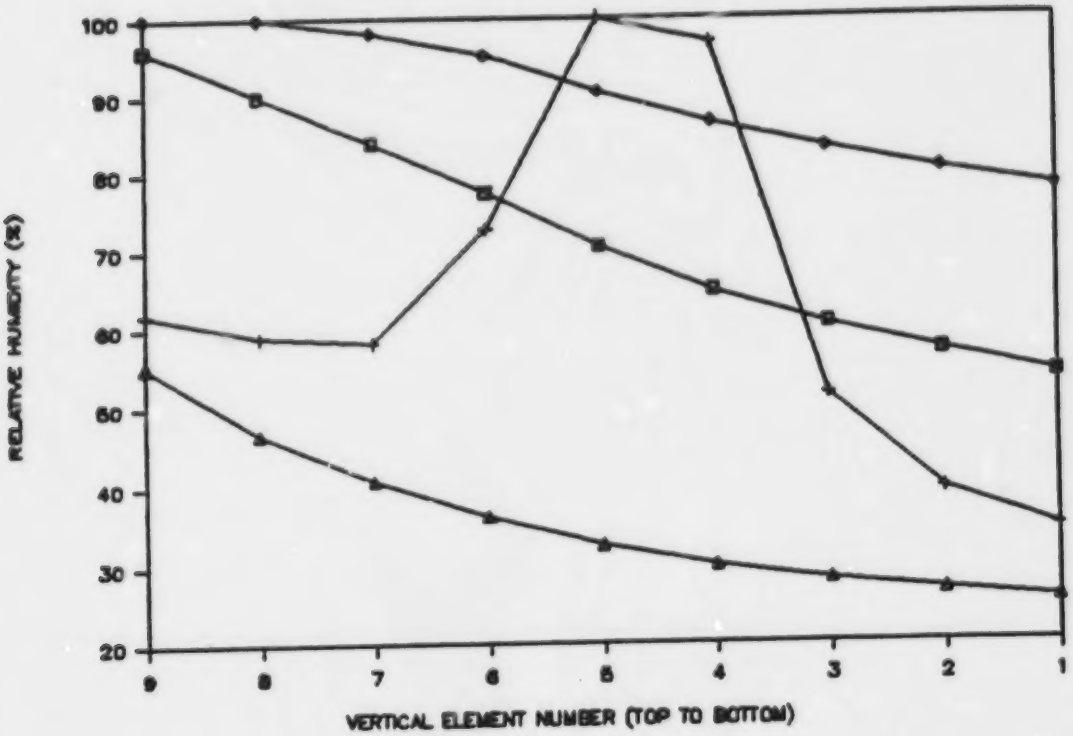
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◆	0	10	0
▲	0	-10	1000

FIGURE 8
DRYING RATE PROFILES
AT LAYER 10

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



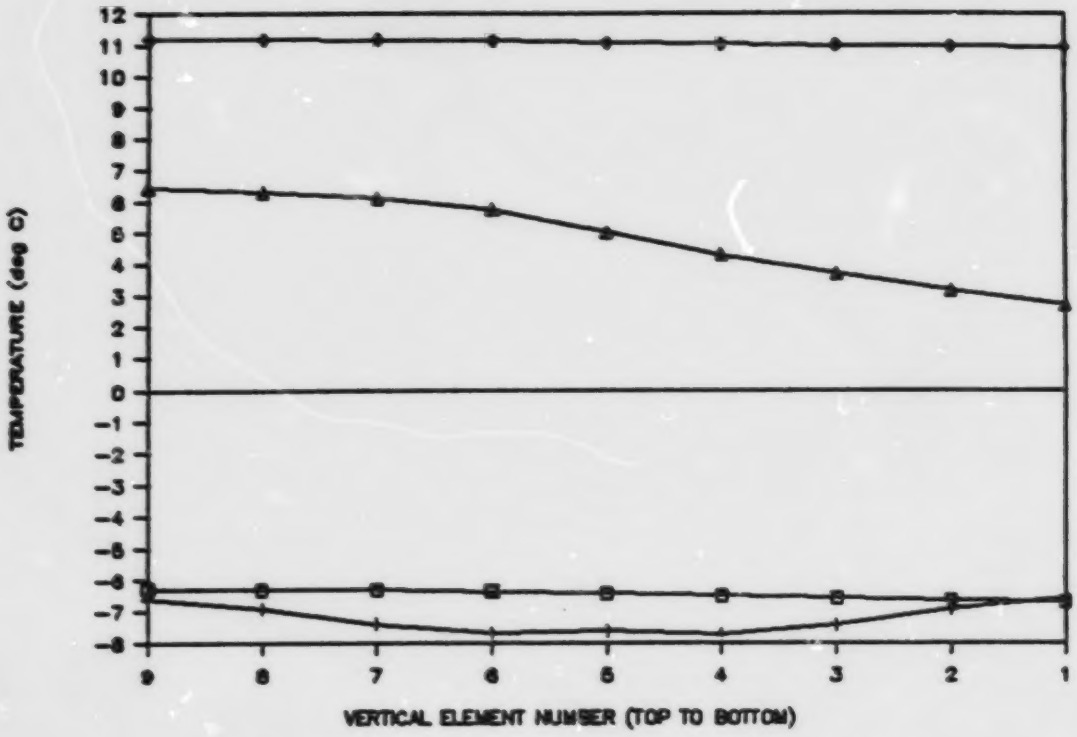
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 9
RELATIVE HUMIDITY PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



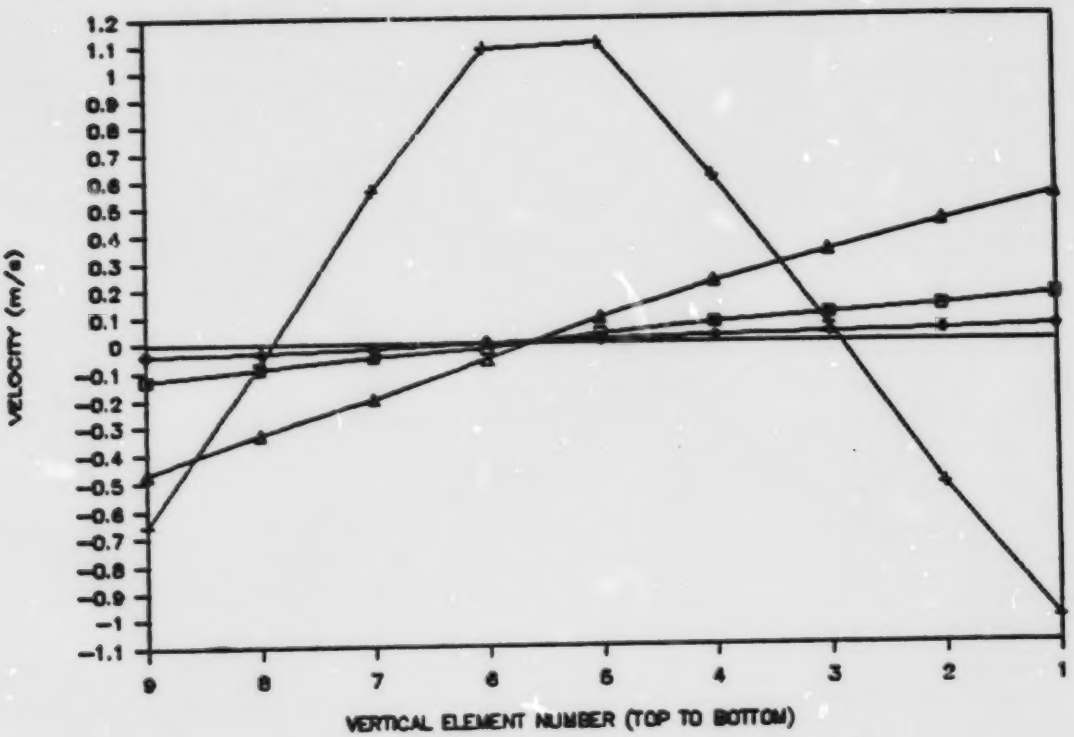
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◊	0	10	0
▲	0	-10	1000

FIGURE 10
TEMPERATURE PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



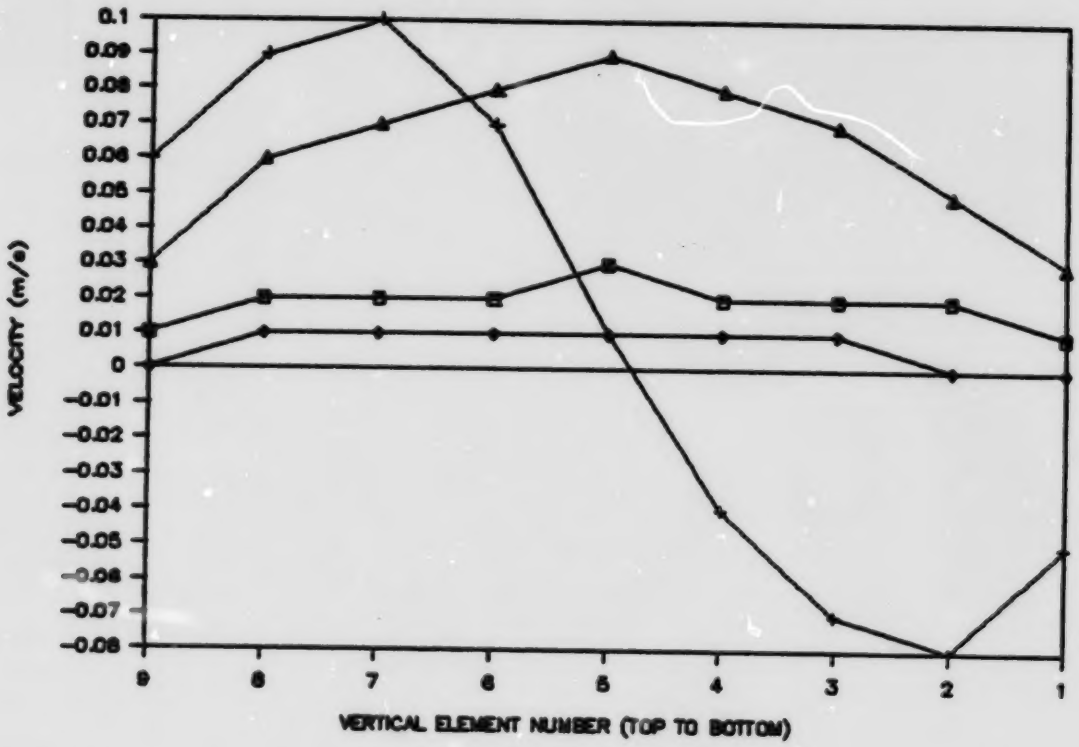
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 11
VELOCITY PROFILES
IN THE GAP

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



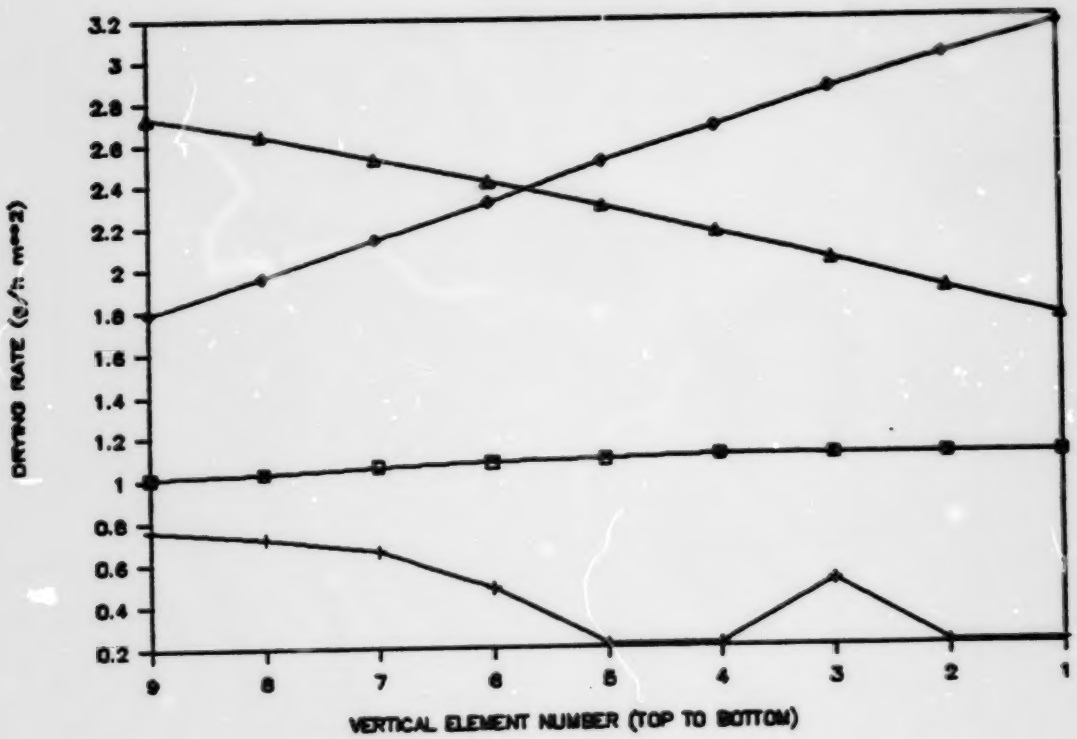
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 12
VELOCITY PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	3 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



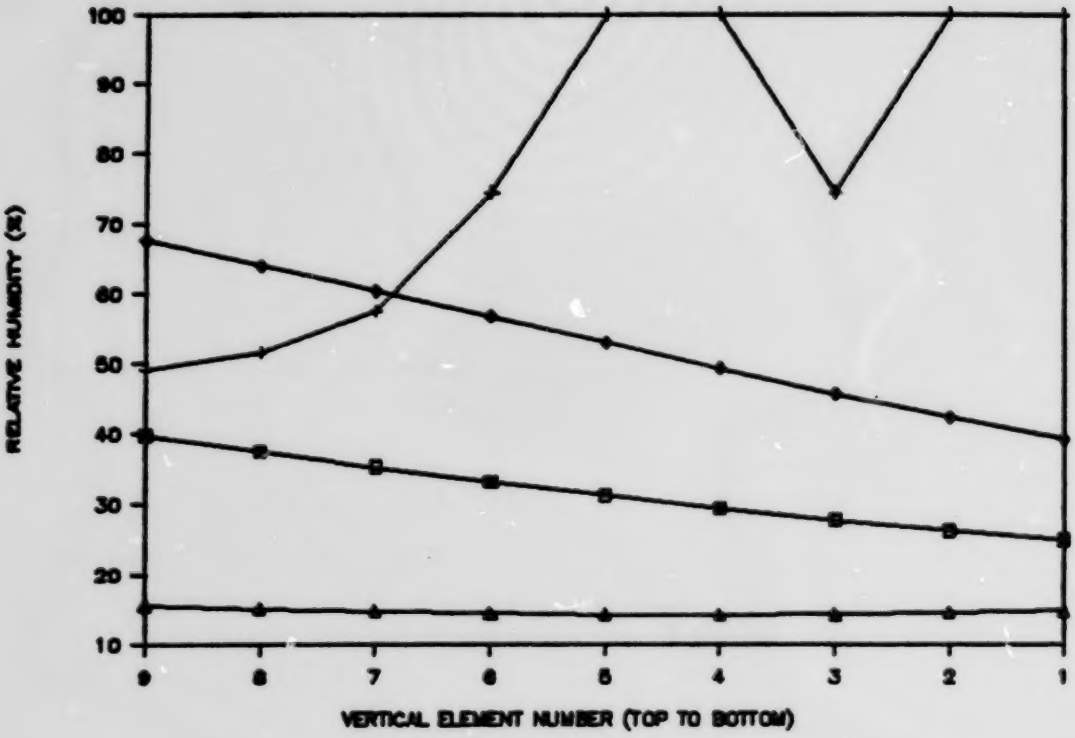
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 13
DRYING RATE PROFILES
AT LAYER 10

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	3 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



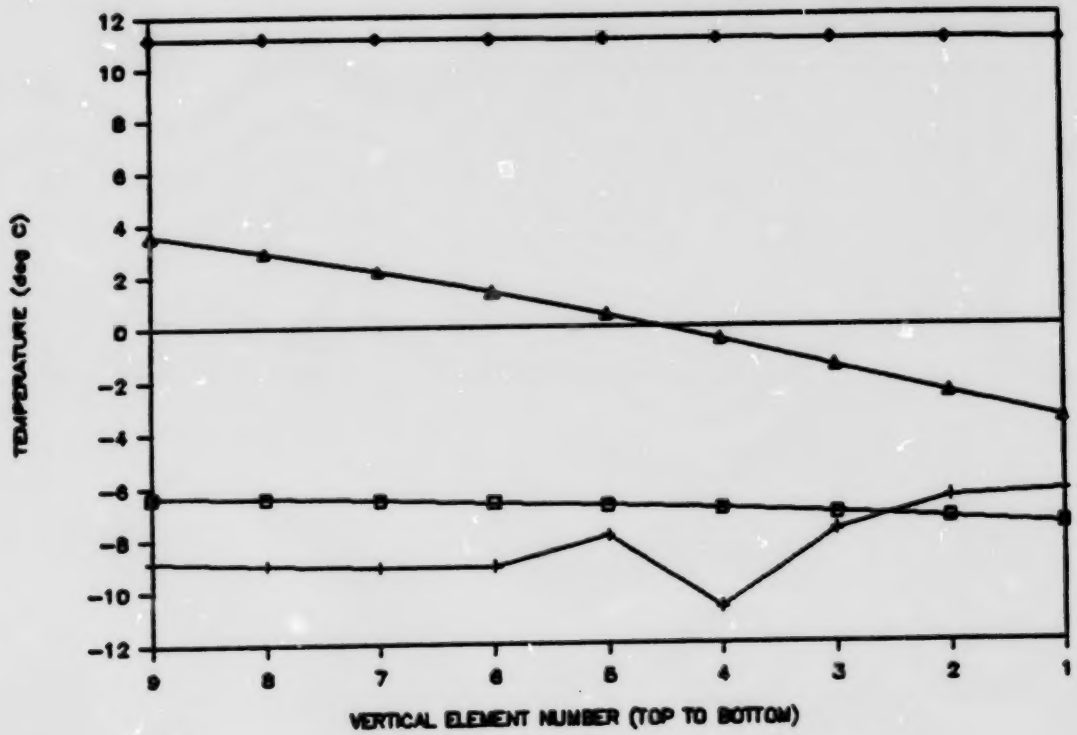
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 14
RELATIVE HUMIDITY PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	3 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



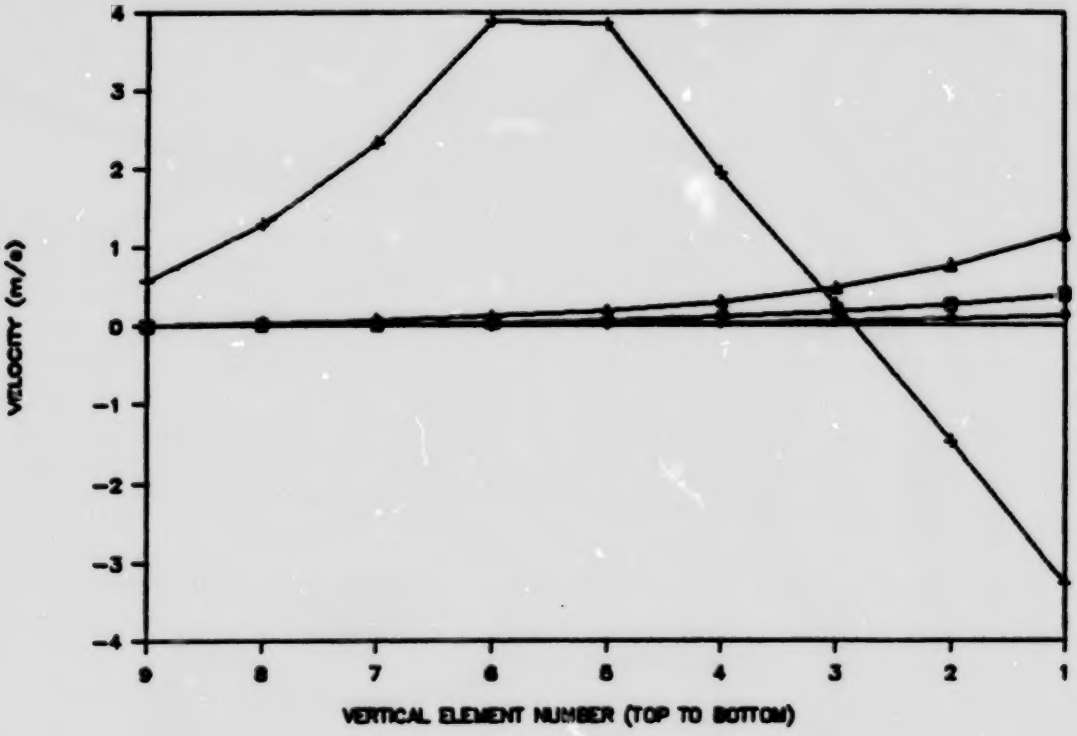
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 15
TEMPERATURE PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	3 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



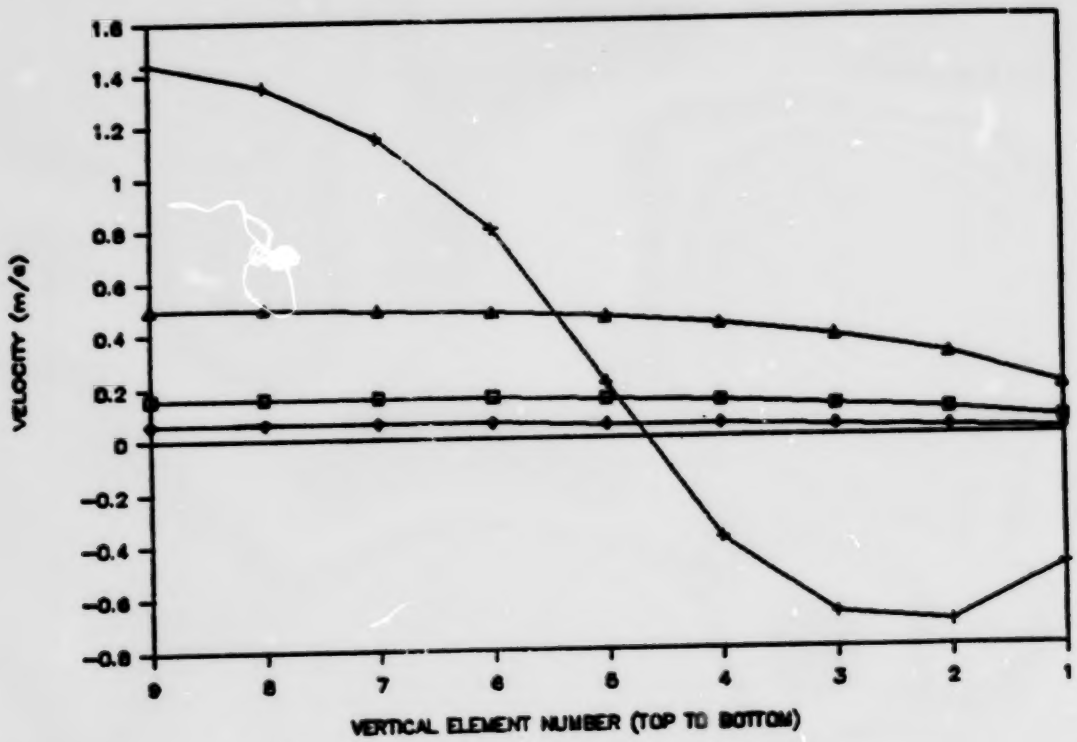
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 16
VELOCITY PROFILES
IN THE GAP

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	3 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



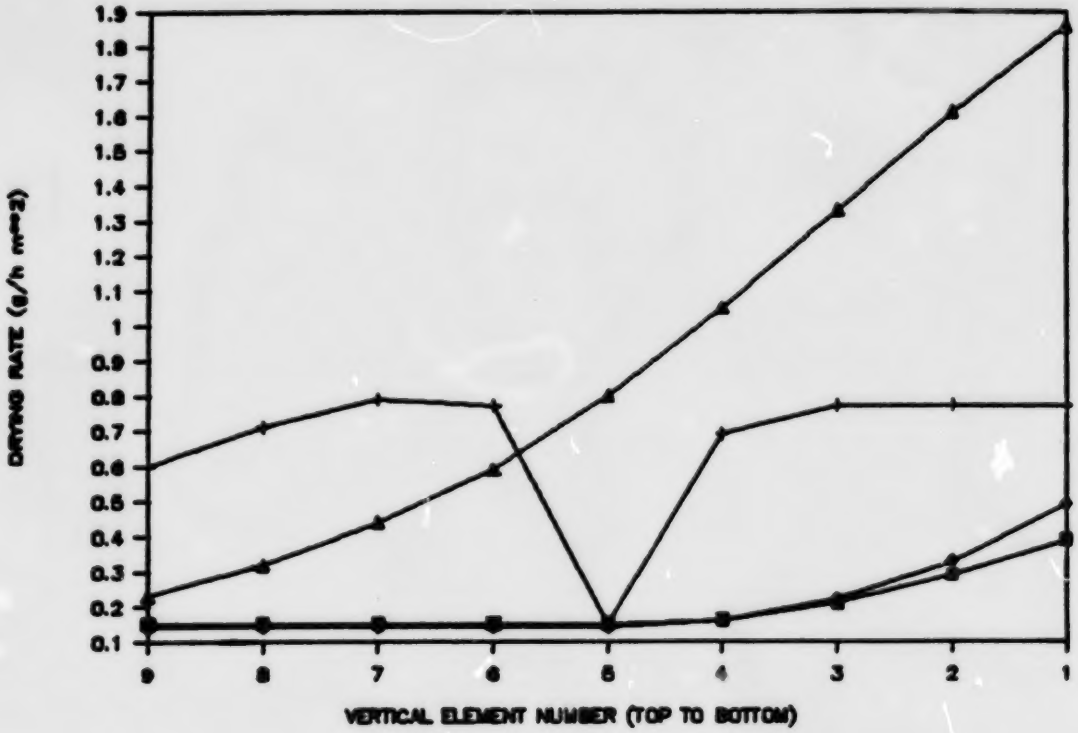
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 17
VELOCITY PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	3 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



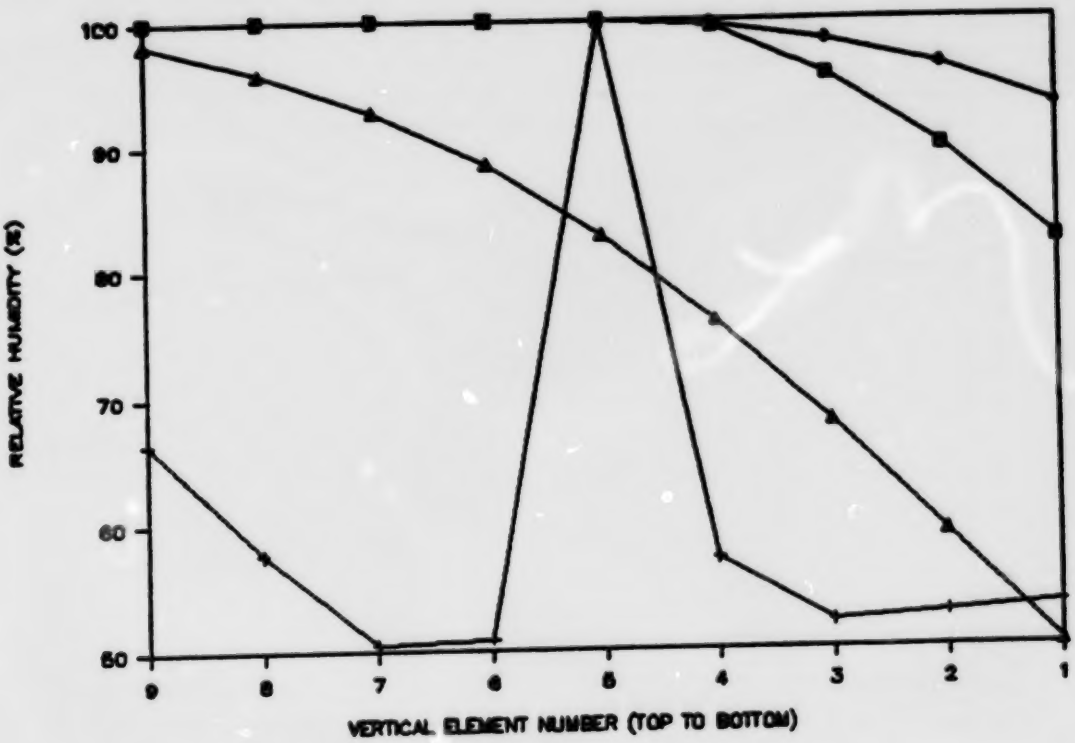
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 18
DRYING RATE PROFILES
AT LAYER 10

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	3 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



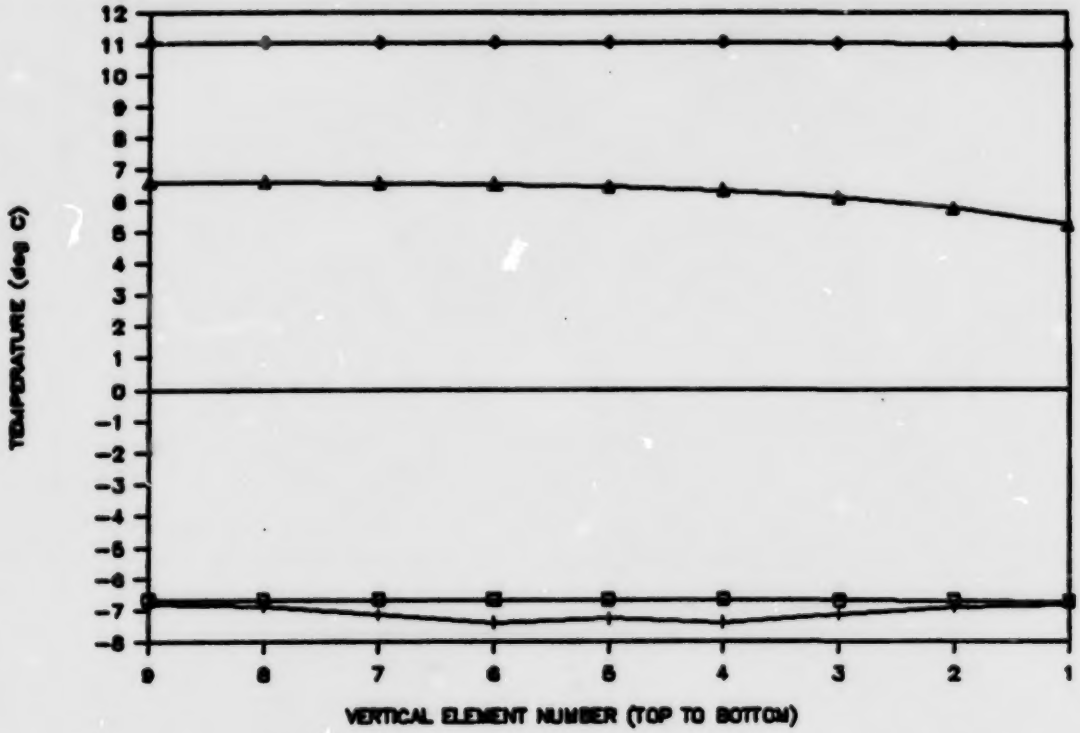
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 19
RELATIVE HUMIDITY PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	3 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



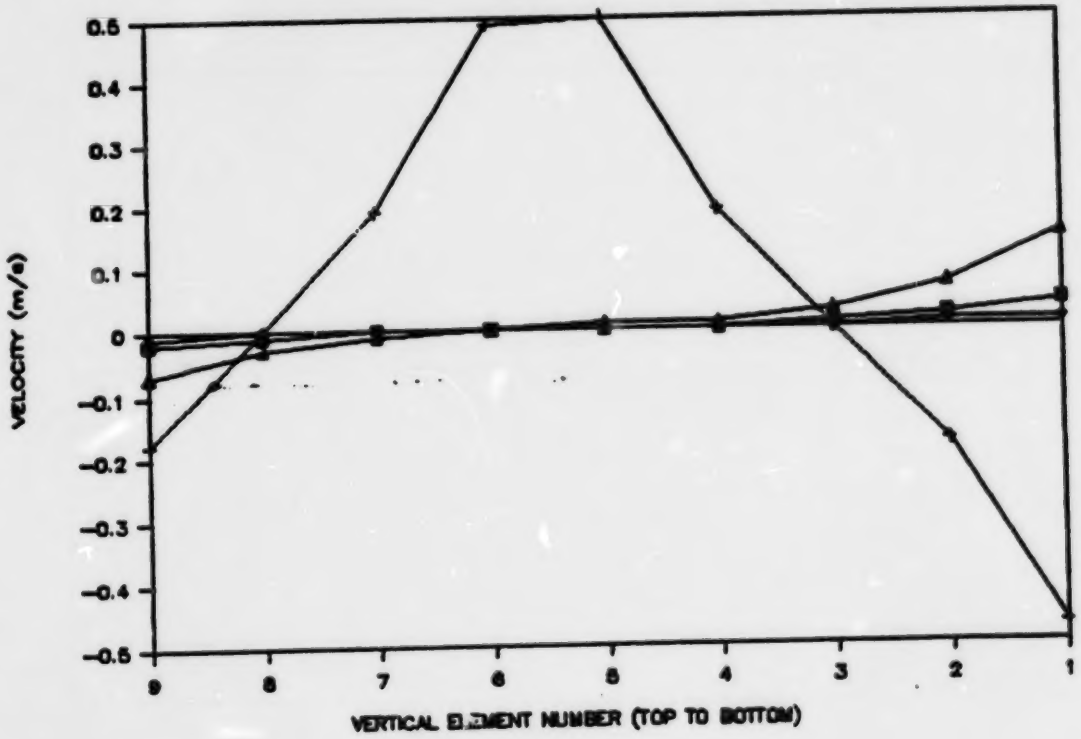
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 20
TEMPERATURE PROFILES
IN THE AIRSPACE

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	3 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



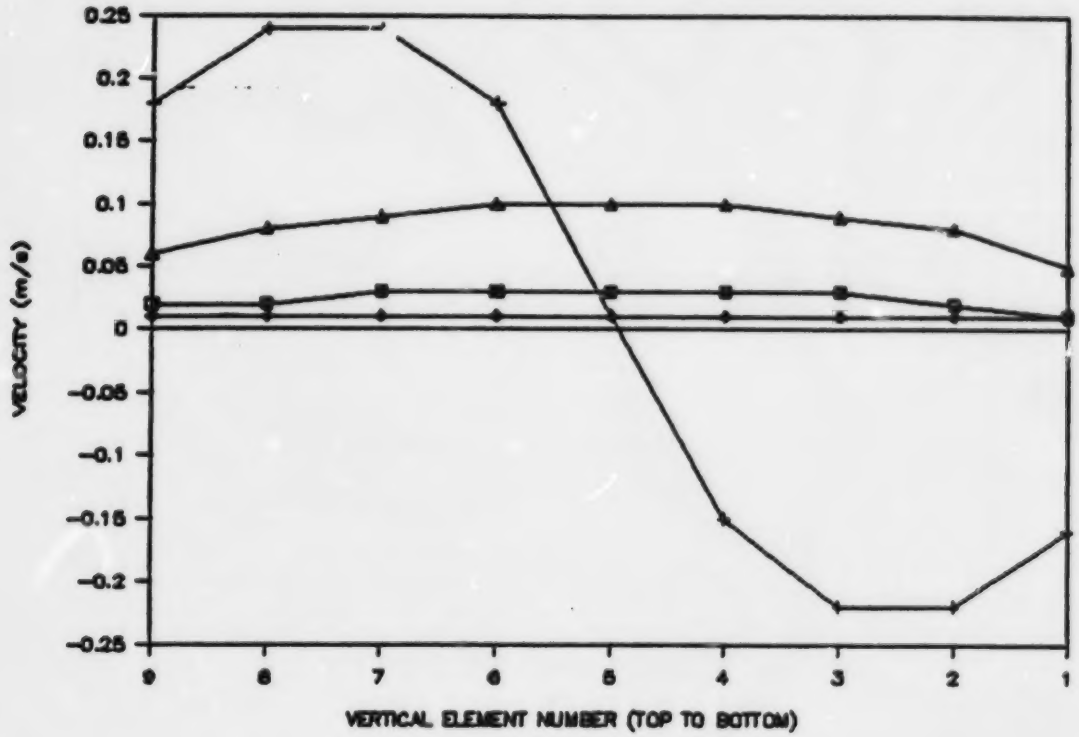
SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 21
VELOCITY PROFILES
IN THE GAP

WALL PROPERTIES

Top Opening:	1 mm
Airspace Thickness:	3 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm
Wall Height:	6 m

Note: All other wall properties are given in Table 2.



SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)
□	0	-10	0
+	20	-10	0
◇	0	10	0
△	0	-10	1000

FIGURE 22
VELOCITY PROFILES
IN THE AIRSPACE

Figures 23 to 25 are the same drying data selected and grouped to show the effect of wall type under different weather conditions.

Using these three graphs, one can judge the general performance of a wall construction compared to other constructions. For example, in this case, the base wall condition (strapping, top opening, 1mm gap) appears to be the best in two of the three weather conditions. In the third case, wider siding gaps appear better. In this comparison, the wall with no strapping and no top opening appears to be the worst. This type of comparison is good for grading performance of construction types, but does not help to judge the adequacy of any wall type or assist in material selection.

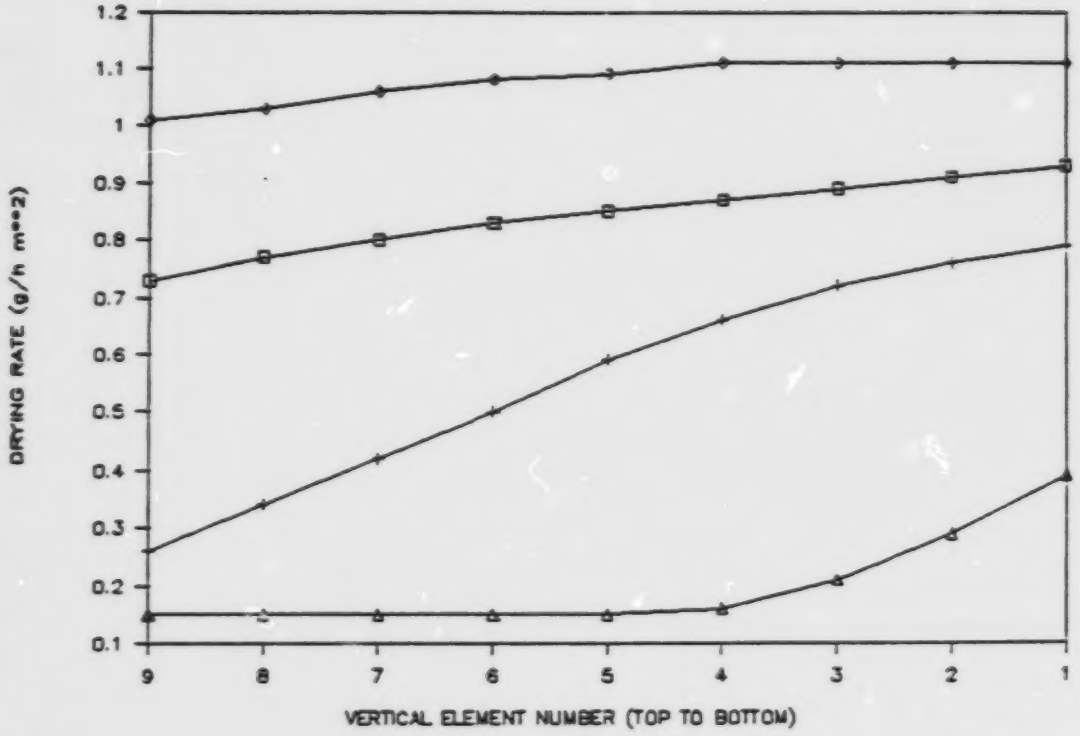
Figure 26 compares the drying rate of the sheating with two different sheathing paper permeabilities. This is accomplished by changing the thickness of the paper from 0.5mm to 1.5mm.

All of Figures 3 to 26 have shown data for a 2 storey wall of 6 metres in height. To investigate the effect that height has on drying, the base wall (i.e. that used for Figures 3 to 7 and described in Table 2) was altered to a height of 2 metres. A comparison of drying rates and airspace velocities for the 2 and 6 metre walls under three different weather conditions is shown in Figures 27 and 28. From these figures it can be seen that there is little difference except when there is high incident solar radiation. In that case, both the airspace velocity and the drying rate are significantly higher for the taller wall.

WEATHER CONDITIONS

Wind Speed(kph): 0

Solar Radiation(W/m^2): 0



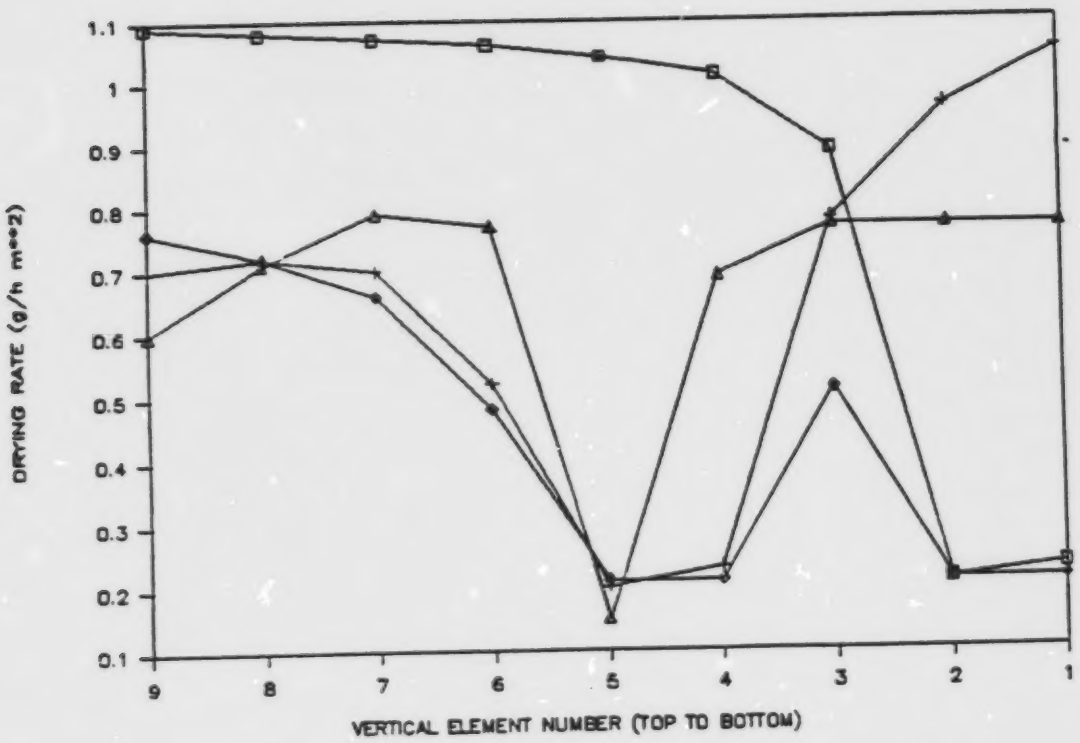
SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	1	1	0.5
◇	20	20	3	0.5
△	3	1	1	0.5

FIGURE 23
COMPARISON OF DRYING RATES AT LAYER 10
FOR DIFFERENT WALL CONSTRUCTIONS

WEATHER CONDITIONS

Wind Speed(kph): 20

Solar Radiation(W/m^2): 0



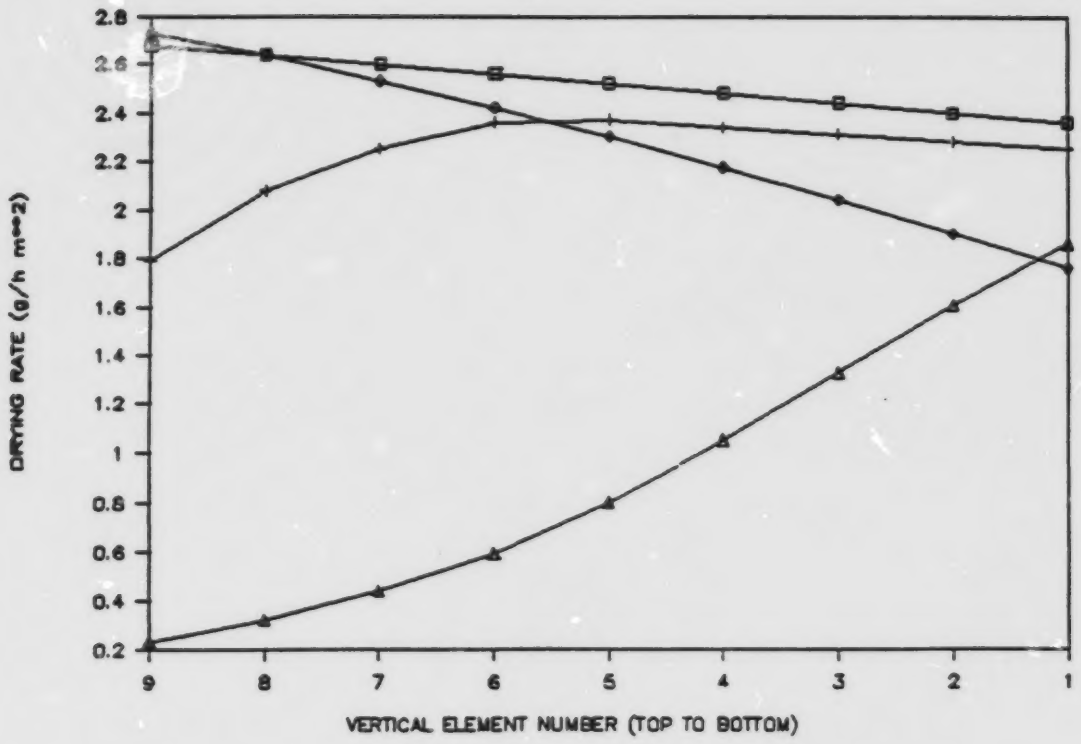
SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	1	1	0.5
◇	20	20	3	0.5
△	3	1	1	0.5

FIGURE 24
COMPARISON OF DRYING RATES AT LAYER 10
FOR DIFFERENT WALL CONSTRUCTIONS

WEATHER CONDITIONS

Wind Speed(kph): 0

Solar
Radiation(W/m^2):1000



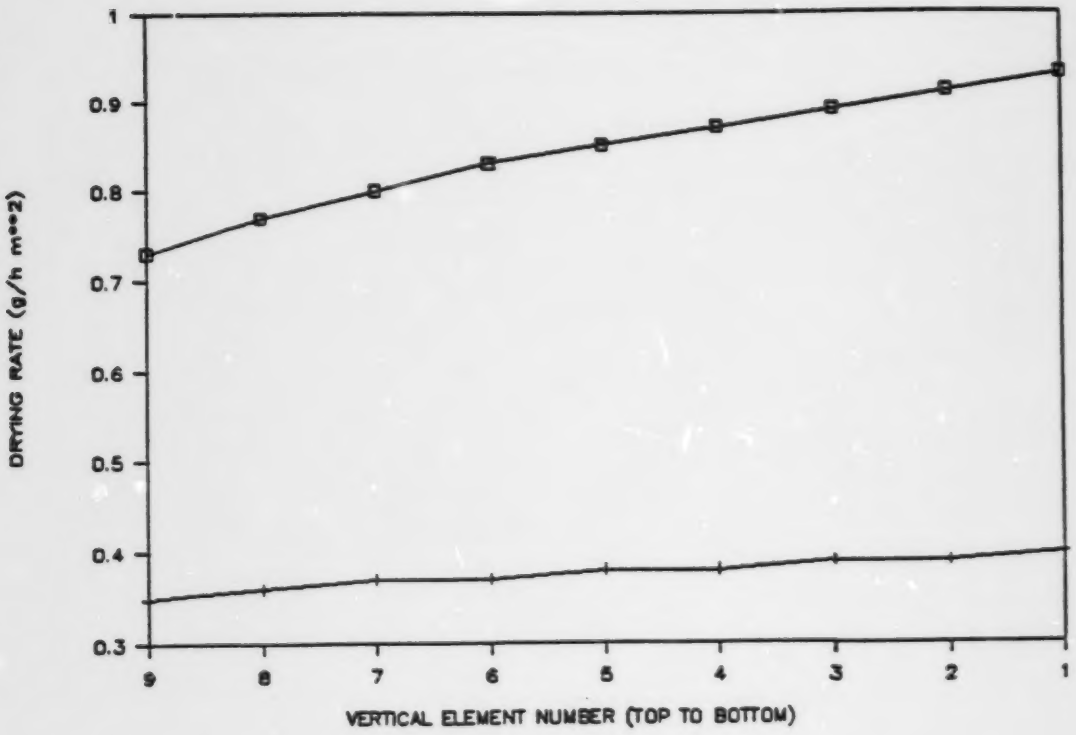
SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	1	1	0.5
◇	20	20	3	0.5
△	3	1	1	0.5

FIGURE 25
COMPARISON OF DRYING RATES AT LAYER 10
FOR DIFFERENT WALL CONSTRUCTIONS

WEATHER CONDITIONS

Wind Speed(kph): 0

Solar
Radiation(W/m^2): 0

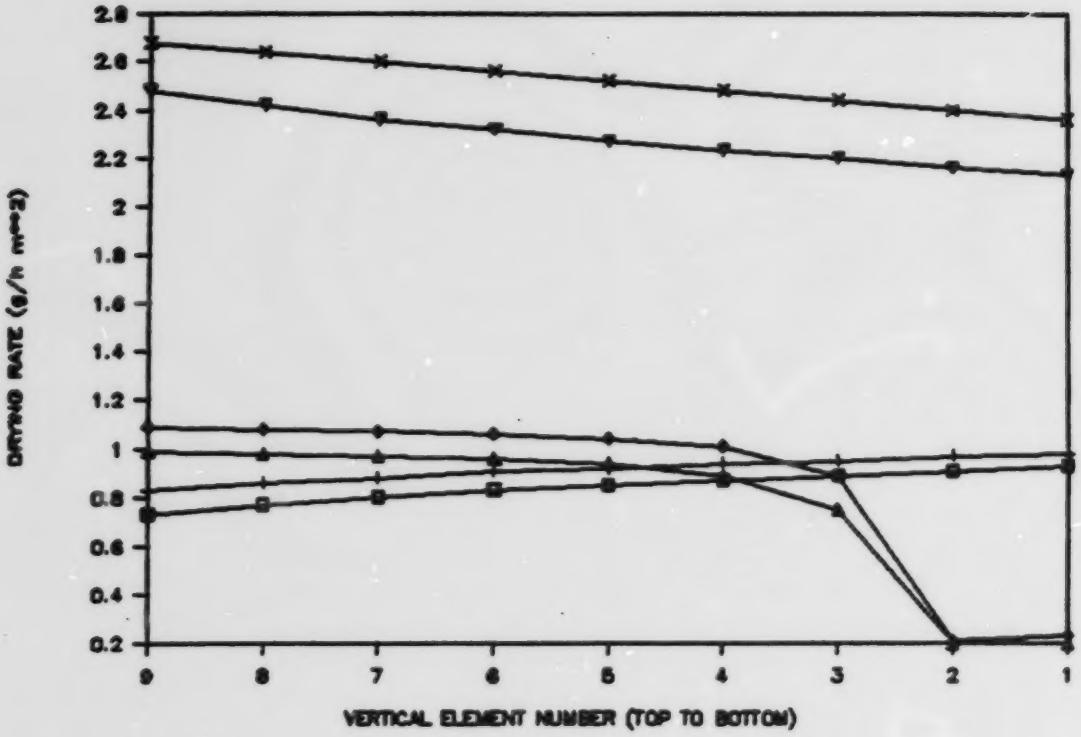


SYMBOL	AIRSPACE THICKNESS (mm)	TOP OPENING (mm)	GAP WIDTH (mm)	SHEATHING PAPER THICKNESS (mm)
□	20	20	1	0.5
+	20	20	1	1.5

FIGURE 26
COMPARISON OF DRYING RATES AT LAYER 10
FOR TWO SHEATHING PAPER THICKNESSES

WALL PROPERTIES

Top Opening: 20 mm
Airspace Thickness: 20 mm
Gap Width: 1 mm
Sheathing Paper Thickness: 0.5 mm

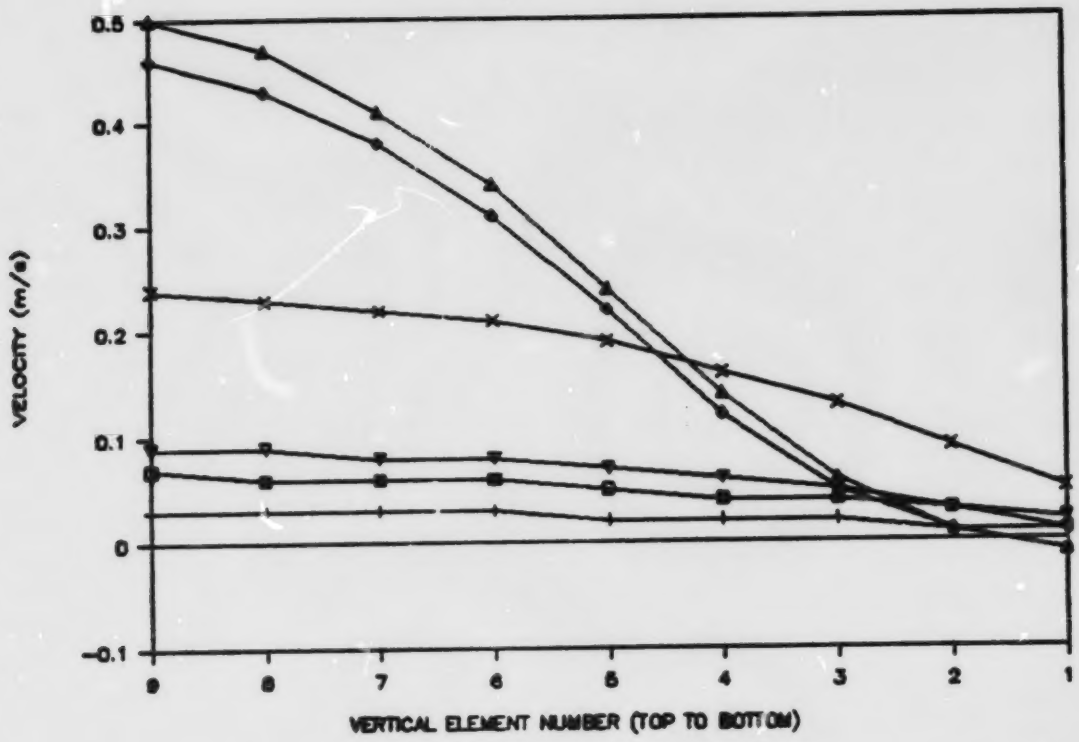


SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)	WALL HEIGHT (m)
□	0	-10	0	6
+	0	-10	0	2
◆	20	-10	0	6
▲	20	-10	0	2
X	0	-10	1000	6
▼	0	-10	1000	2

FIGURE 27
COMPARISON OF DRYING RATES AT LAYER 10
FOR TWO DIFFERENT WALL HEIGHTS

WALL PROPERTIES

Top Opening:	20 mm
Airspace Thickness:	20 mm
Gap Width:	1 mm
Sheathing Paper Thickness:	0.5 mm



SYMBOL	WIND SPEED (kph)	OUTDOOR AIR TEMP. (C)	SOLAR RADIATION (W/m^2)	WALL HEIGHT (m)
□	0	-10	0	6
+	0	-10	0	2
◇	20	-10	0	6
△	20	-10	0	2
X	0	-10	1000	6
▽	0	-10	1000	2

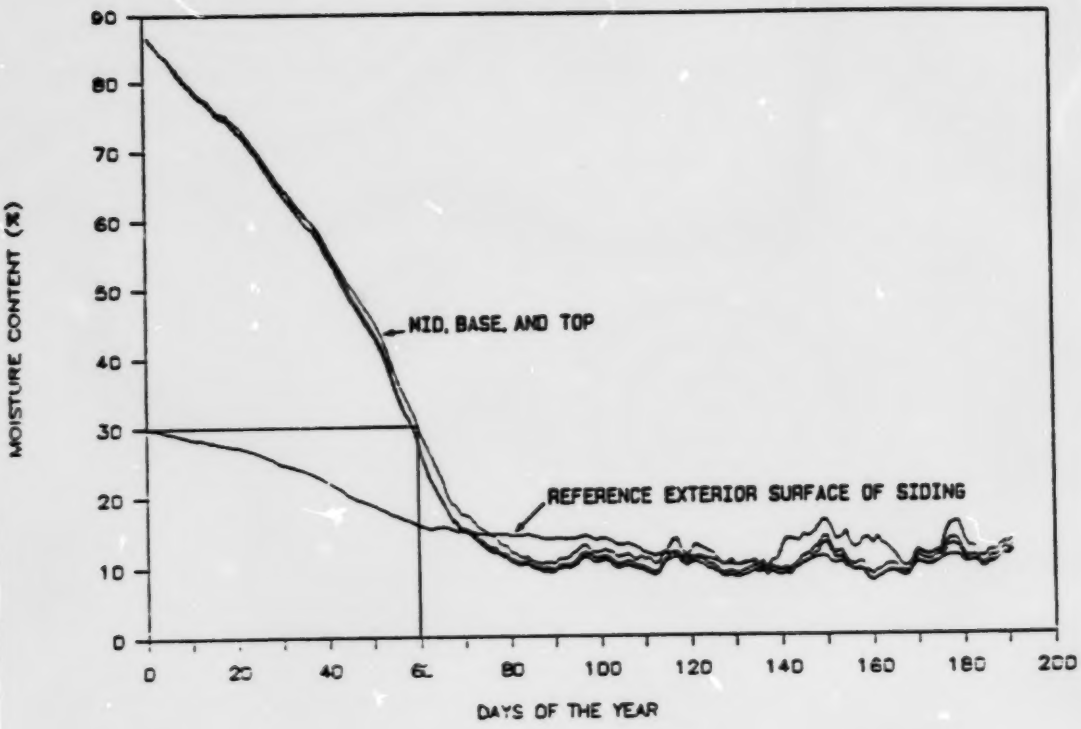
FIGURE 28
COMPARISON OF AIRSPACE VELOCITIES
FOR TWO DIFFERENT WALL HEIGHTS

3.3 Time Histories

Figures 29 to 32 are time histories of moisture content in layer 10 (sheathing) at the top, middle and bottom of the wall. The weather data used was taken from weather data tapes for Halifax, 1974. Figures 29 and 30 represent a wall with 20mm strapping while Figures 31 and 32 represent a wall without strapping. By comparison of Figures 29 and 31 or Figures 30 and 32, the effect of strapping can be seen. The walls have initially 88% moisture content by weight and are allowed to dry without moisture input other than from the outside air.

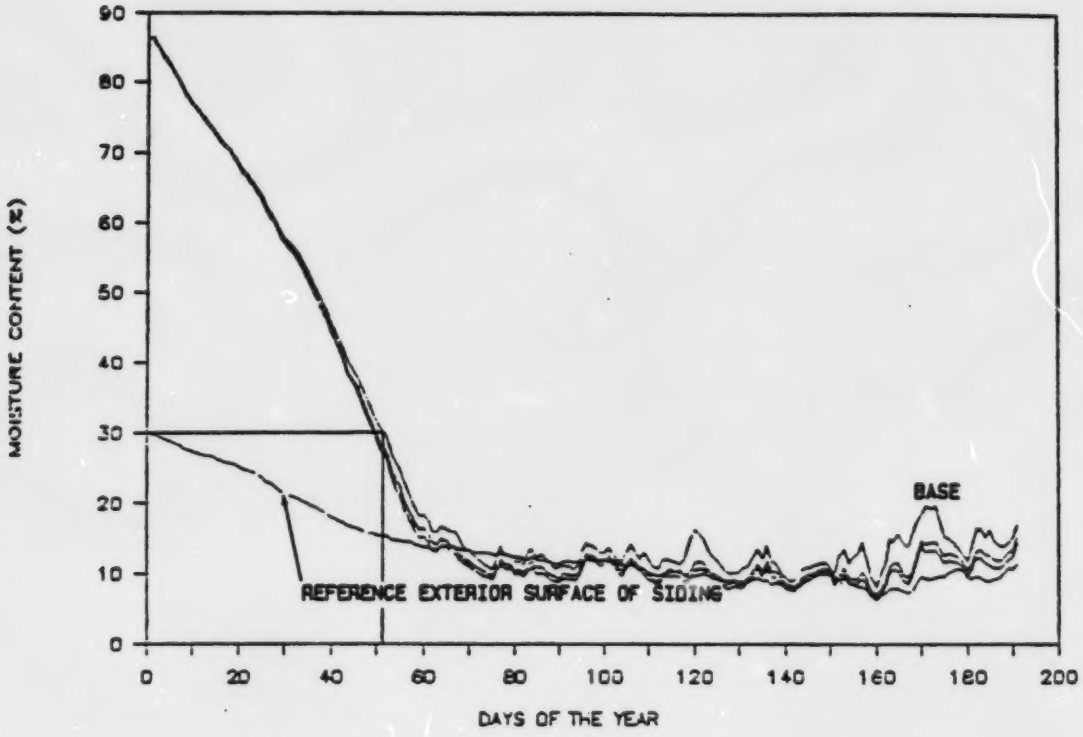
As a method of comparison, the time required to reach 30% could be used. This is shown on the figures. From this comparison we find that the unstrapped wall takes from 28% to 133% longer to reach 30% moisture content than the strapped wall. A similar comparison between north and south walls shows that north facing walls take from 15% to 43% longer than south facing walls to dry to 30%.

The graphs also show that in the strapped wall, the top dries as quickly as the bottom. In the case of the unstrapped walls, however, the top takes from 66% to 79% longer to dry than the bottom.



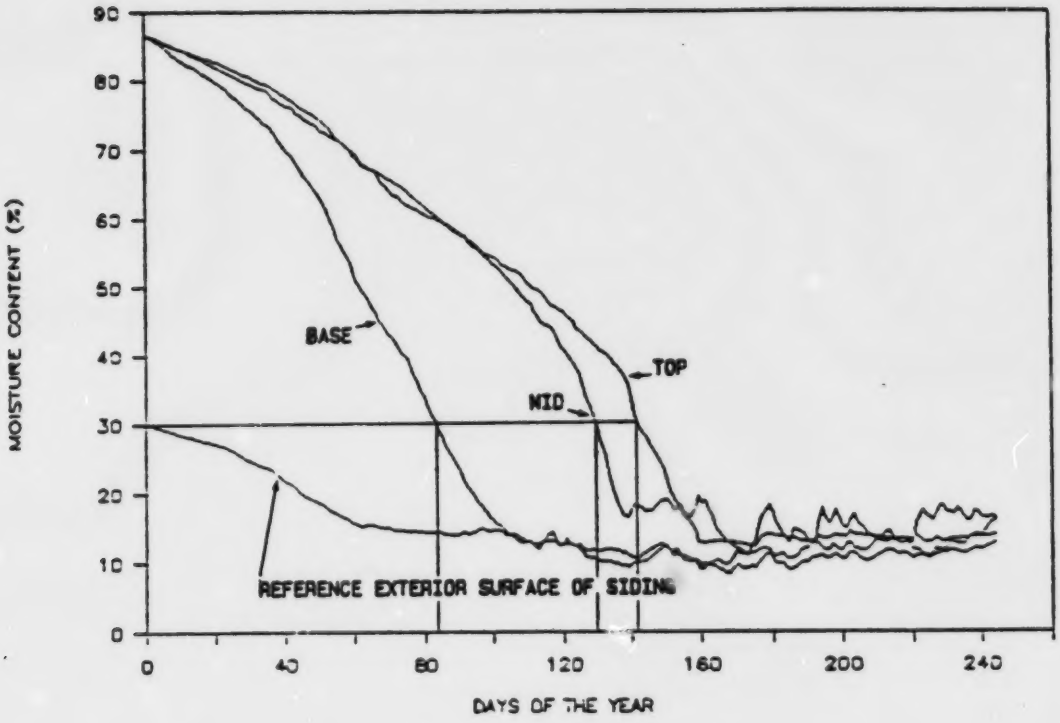
HALIFAX - north facing,with strapping

FIGURE 29
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE



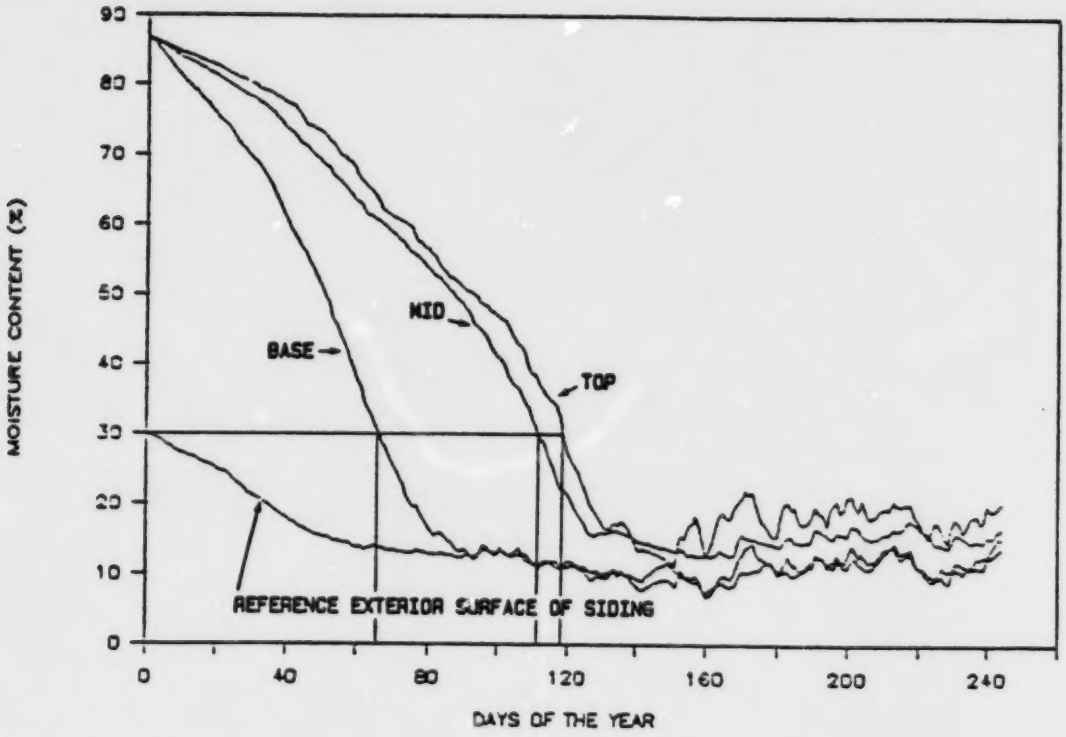
HALIFAX - south facing,with strapping

FIGURE 30
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE



HALIFAX - north facing,without strapping

FIGURE 31
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE



HALIFAX - south facing,without strapping

FIGURE 32
MOISTURE CONTENT TIME HISTORIES
EXTERIOR SHEATHING SURFACE

4. CONCLUSIONS

As an element of experimental research, the development of a computer model has proven to be an efficient method of assembling available information. The model as developed provides a skeletal framework that can act as a development tool. It allows researchers to test hypotheses and organize further research to prevent duplication of effort. The comparison of model predictions to experimental results could demonstrate the completeness of our understanding of moisture migration within walls or delineate the importance of parameters not previously considered important.

Accordingly, the model must be considered as the nucleus of further achievement for the Canada Mortgage and housing Corporation and for other researchers.

The model has been demonstrated in its three different operational modes. These are:

1) Providing basic information on the migration of heat, air and moisture within the wall;

2) Grading the relative performance of different wall constructions under standard conditions; and

3) Grading the relative long performance of different wall constructions in the presence of real weather conditions.

Up to this point the model has proven to be responsive to climatic and construction differences. As yet, however, it has not been validated against real laboratory or field data. It also lacks some physical properties that it was originally intended to include. The most important of these are a proper radiation

balance at the exterior surface, gravity drainage and a model of rain penetration. These require some further model development. In the case of the radiation balance it was felt that this could be left out until a shading model was developed. In the case of the rain penetration and drainage models further research is required before realistic models can be developed.

The calibration or validation procedure along with the development described above are the next steps required to provide confidence in the use of the model for design of new wall types or the troubleshooting of existing walls.

APPENDICES

APPENDIX A

BIBLIOGRAPHY

BIBLIOGRAPHY

1 ASHRAE — ASHRAE Handbook 1981 Fundamentals, ASHRAE Inc. 1981

2 ASTM — "Standard Test Methods for Water Vapour Transmission of Materials in Sheet Form. ASTM E96-66 (Reapproved 1972)" Annual Book of ASTM Standards. Philadelphia, P.A.: American Society for Testing and Materials, 1978, pt. 18, p. 743 - 750.

3 Achenbach, P.R. ed. — The National Program Plan for the Thermal Performance of Building Envelope Systems and Materials. ORNL/Sub-7973/1. Oak Ridge, Tenn.: Oak Ridge National Laboratory, 1982.

4 Achenbach, Paul R. — "Use of Ventilation for Moisture Control", ASTM Standardization News, November 1984, pp. 32 - 34.

5 Allen, Carolyn — Leakage Distribution in Buildings

6 Anderson, Ann Charlotte — Verification of Calculation Methods for Moisture Transport in Porous Building Materials, Swedish Council for Building Research, D6-1985, Stockholme, Sweden.

7 Ball, W.H. and V.F. Lyman — The Control of Rain Wetting and Penetration of Brick-Clad Masonry Walls, Prepared for Journal of the Royal Architectural Institute of Canada, Division of Building Research, National Research Council Canada, Ottawa, Feb. 1966.

8 Bassett, M.R. and H.A. Trethowan — "Effect of Condensation on Emittance of Reflective Insulation", Journal of Thermal Insulation Vol. 8, pp. 127 - 135, Oct. 1984.

9	Baumgardner, R.L.	"Solving the Moisture Problem", ASTM Standardization News, November 1984, pp. 24 - 25.
10	Becker, R.	"Condensation and Mould Growth in Dwellings - Parametric and Field Study". Building and Environment, Vol. 19, No. 4, pp. 243 - 250, 1984.
11	Becker, R. and C. Jaegermann	"The Influence of Permeability of Materials and Absorption on Condensation in Dwellings", Building and Environment, Vol. 17, No. 2, pp. 125 - 134, 1982.
12	Berg, Robert J.	"Moisture in Walls and Floors", ASTM Standardization News, Nov. 1984, pp. 29 - 31.
13	Berger, D. and D.C.T. Pei	"Drying of Hygroscopic Capillary Porous Solids - A Theoretical Approach", Int. J. Heat Mass Transfer, Vol. 16, pp. 293 - 302, 1973.
14	Bhargava, Jetendra K.	"Measurement of Moisture and Moisture Profile in Floor Constructions", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, September 1974.
15	Billington, Neville S.	"Building Physics: Heat", Pergamon Press Oxford (1967).
16	Birkeland, O.	"General Raport: Rain Penetration" RILEM/CIB Symposium of Moisture Problems in Buildings, Otaniemi, Finland. August 16-19, 1965.
17	Bjertnaes, Leif Thore and Annanias Tveit	"Measurement of Water Diffusivity of Porous Materials", 2nd International RILEM/CIB Symposium on Moisture Problems in Buildings, September 1974.
18	Blackall, T.N. and M.C. Baker	Rain Leakage of Residential Windows in the Lower Mainland of British Columbia, Building Practice Note no. 42, Ottawa: DBR/NRCC, 1984.
19	Bloomfield, D.P.	"Condensation Risk in Intermittently Heated Rooms", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, September 1974.

20 Bogle, A., J.T. McMullan and R. Morgan — "An Experimental Examination of the Effects of Rainfall on the Heat Loss from a Red Brick Wall", Energy Research, Vol. 8, pp. 1 - 18, 1984.

21 Bomberg, M. — Laboratory Methods for Determining Moisture Absorption of Thermal Insulations I: Review DBR Paper No. 1114. Ottawa: Division of Building Research, National Research Council of Canada, 1983.

22 Bomberg, Mark — Water Flow Through Porous Materials Part I: Methods of Water Transport Measurements, Division of Building Technology, Lund Institute of Technology, Lund Sweden, Report 19, 1971.

23 Bomberg, Mark — Water Flow Through Porous Materials Part III: Applications of the Relative Suction Model, Division of Building Technology, Lund Institute of Technology, Lund Sweden, Report 21, 1972.

24 Bomberg, Mark — Moisture Flow Through Porous Building Materials, Division of Building Technology, Lund Institute of Technology, (Lund Sweden) Report 52, 1974.

25 Bomberg, Mark — Development of Thermal Insulation Performance Test Methods. DBR Paper No. 1096 Ottawa: Division of Building Research, National Research Council of Canada, 1982.

26 Bomberg, M. and M.K. Kumaran — A Test Method to Determine Air Flow Resistance of Exterior Membranes and Sheathings. Building Research Bote No. 227, Ottawa: DBR/NRCC, April, 1985.

27 Bomberg, M. and C.J. Shirtliffe — "Influence of Moisture and Moisture Gradients on Heat Transfer Through Porous Building Materials", Thermal Transmission Measurements of Insulation, ASTM 660, R.P. Tye, Ed., 1978, pp. 211-233.

28 Bouyoucos, George, J. and R.L. Cook — "Humidity Sensor: Permanent Electric Hygrometer for Continuous Measurement of the Relative Humidity of the Air(1)" RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, Aug. 16-19, 1965.

29 Boyd, D.W. — Weather and the Deterioration of Building Materials, National Research Council of Canada, Division of Building Research, Paper No. 933, 1980 (NRCC 18635Z).

30	Boyd, D.W.	Driving Rain Map of Canada, National Research Council of Canada, Division of Building Research, Technical Note 398, May 1963.
31	Brackley, G.	The Variability of the Measurement of Water tightness of Joints, Building Research Establishment, Princes Risborough Laboratory, CP6, 1983.
32	Brdlik, P.M., I.A. Kozinov and N.G. Petrov	"An Experimental Investigation of Heat-Mass-Transfer During Condensation of Water-Vapour from Humid Air on the Vertical Surface under Conditions of Natural Convection" RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.
33	Burch, Douglas.	"Experimental Validation of a Mathematical Model for Predicting Moisture Transfer in Attics". Moisture and Humidity, 1985. Proceedings of the 1985 International Symposium on Moisture and Humidity, Washington, D.C. April 15 - 18, 1985.
34	Burch, Douglas M., Robert G. Mathey, and Walter J. Rossiter, Jr.	"Moisture and Roof Performance", ASTM Standardization News, Nov. 1984, pp. 26 - 28.
35	Burch, Douglas, M.; Stephen, J. Treado, and Antonio G. Contreras	"The Use of Low-Permeability Insulation as an Exterior Retrofit System - A Condensation Study". ASHRAE Transactions 95, pt.2 pp. 547-562, 1979
36	Burch, Douglas M. and D.E. Luna	" A Mathematical Model for Predicting Attic Ventilation Rates Required for Preventing Condensation on Roof Sheathing". ASHRAE Transactions, Vol.86, Part 1, 1980.
37	Cammerer, J.S.	"The Influence of Humidity on the Thermal Conductivity Coefficients of Building Materials According to the International Literature. Translated by D.A. Sinclair Ottawa: DBR/NRCC TT-1160, 1964.

38 Cammerer, Walter F. "The Capillary Motion of Moisture in Building Materials in Building Materials", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, Rotterdam, September 1974.

39 Canadian Government Specifications Board Sheathing, Membrane, Breather Type National Standard of Canada CAN2-51.32-M77. Ottawa: Canadian Government Specifications Board, 1977.

40 Canada Mortgage and Housing Corp. Energy Efficient Housing Construction. NHA 5488 - 82/11. Ottawa: Canada Mortgage and Housing Corporation, 1982.

41 Chang, S.C. and N.B. Hutcheon Dependence of Water Vapor Permeability on Temperature and Humidity, Research Paper No. 21 DBR/NRCC, Ottawa. March 1956 (NRC No. 3922).

42 Claesson, Johan "Fundamentals of Moisture and Energy Flow in Capillary - Porous Building Materials", Energy Conservation in Heating, Cooling and Ventilating Buildings, C.J. Hoogendoorn and N.H. Afgan, Vol. 1, Hemisphere Publishing Corp, 1978.

43 Cleary, P.G. "Moisture Control by Attic Ventilation - An In Situ Study" ASHRAE Paper No. 2872 ASHRAE Winter Meeting, Chicago, January 1985.

44 Cleary, Peter and Max Sherman "Seasonal Storage of Moisture in Roof Sheathing", Moisture and Humidity 1985 Measurement and Control in Science and Industry, Proceedings 1985 Int. Symposium on Moisture and Humidity, Washington, D.C., April 15 - 18, 1985, pp. 313 - 323.

45 Cleary, Peter and Robert Sonderegger "A Method to Predict the Hour by Hour Humidity Ratio in Attic Air", Presented at the ASTM Symposium on Thermal Insulation, Materials and Systems, Dec. 2-6, 1984, Dallas, Texas.

46 Comini, G. and S. Del Giudice "Finite Element Analysis of Heat and Mass Transfer in Buildings", Energy Conservation in Heating, Cooling and Ventilating Buildings, Hoogendoorn, C.J. and N.H. Afgan, Vol. 1, Hemisphere Publishing Corporation, 1978.

47 Comini, G. and R.W. Lewis — "A Numerical Solution of Two-Dimensional Problems Involving Heat and Mass Transfer", Int. J. Heat Mass Transfer, Vol. 19, pp. 1387-1392, 1976.

48 Condon, P.E. and William L. Carroll — "Measurement and Analysis of in-situ Dynamic Thermal Performance of Building Envelopes Using Heat Flow Meter Arrays". ASHRAE/DOE Conference on Thermal Performance of Exterior Envelopes of Buildings. ASHRAE SP28, pp. 740-750, 1981.

49 Coon, David — Indoor Air Quality in Tight Houses: A Literature Review. Toronto: Housing Conservation Unit, Ontario Ministry of Municipal Affairs and Housing, 1984.

50 Cunningham, M.J. — A New Analytical Model to Describe the Time Dependant Behaviour of Moisture Concentrations in Building Cavities. Unpublished (from M. Bomberg).

51 Cunningham, M.J. — "A New Analytical Approach to the Long Term Behaviour of Moisture Concentrations in Building Cavities - I Non-Condensing Cavity", Building and Environment, Vol. 18, No. 3. pp. 109-116, 1983.

52 Cunningham, M.J. — "A New Analytical Approach to the Long Term Behaviour of Moisture Concentrations in Building Cavities II Condensing Cavity", Building and Environment, Vol. 18, No. 3, pp. 112 - 124, 1983.

53 Cunningham, M.J. — "Further Analytical Studies of Building Cavity Moisture Concentrations". Building and Environment Vol. 19 No. 1, pp. 21 - 29, 1984.

54 Cunningham, M.J. — "Automatic Datalogging Timber Moisture Contents Over the Range 10% - 50% w/w, Moisture and Humidity 1985, Proceedings of the 1985 International Symposium on Moisture and Humidity, Washington, D.C., April 15 - 18, 1985.

55 Cvetkevic, Miroslav Z. — "Water Vapour Diffusivity Measurements in Situ", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, September 1974.

56 Davidesco, Al — "Quelgues Aspects de la Thermdiffusion des Vapeurs a Travers des Elements de Construction" RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.

57 Dawance, G. — "Rapport General: La Mesure de L'Humidite en Place". RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.

58 Dechow, F.J. and K.A. Epstein — "Laboratory and Field Investigation of Moisture Absorption and Its Effect on Thermal Performance of Various Insulations", Thermal Transmission Measurements of Insulation, ASTM 660, R.P. Tye, Ed., 1978, pp. 234-260.

59 Demars, Y. and Buck, Y. — "Water Vapour Diffusion Through Insulated Masonry Building Walls", Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds., American Soceity for Testing and Materials, 1982, pp. 110-120.

60 Dickens, H.B. and N.B. Hutcheon — Moisture Accumulation in Roof Spaces Under Extreme Winter Conditions, Technical Paper No. 228, Division of Building Research, National Research Council of Canada, July 1966. (NRC 9132).

61 Dinulescu, H.A. and E.R.G. Eckert — "Analysis of One-Dimensional Moisture Migration Caused by Temperature Gradients in a Porous Medium", Int. Journal of Heat and Mass Transfer, Vol. 23, 1980, pp. 1069-1078.

62 Dumitriu-Valcea, E.J. — "Method for Vapor Diffusion Behaviour Determination of the Building Envelope", Journal of Thermal Insulation, Vol. 7, April 1984, pp. 309-333.

63 Eakes, Jon — Insulation Aftermath: The Canadian Answer Book to Home Insulation Conflict and Confusion, Ontario Marketing Productions Limited, Toronto, 1982.

64 Eckert, E.R.G. — Introduction to Heat and Mass Transfer, McGraw Hill 1963.

65 Eckert, E.R.G. and M. Faghri — "A General Analysis of Moisture Migration Caused by Temperature Differences in an Unsaturated Porous Medium", International Journal of Heat and Mass Transfer, Vol. 123, pp. 1613-1623, 1980.

66 Edenholm, H. Moisture Movement and Moisture Distribution in the Walls of Buildings (Swedish), NRCC TT-361, 1952.

67 Eyre, D. A Dissertation on Residential Energy Conservation and Moisture Damage, Saskatchewan Research Council Publication No. R-825-20-E-84, June 1984.

68 Eyre D., and D. Jennings Air-Vapour Barriers, Saskatchewan Research Council, Publication No. E-825-2-E-81, March 1981.

69 Facaoaru, Ioan "Non-Destructive Methods for Moisture Measurements in Building", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, Sept. 1974.

70 Feldman, R.F. and P.J. Sereda Moisture Content - Its Significance and Interaction in a Porous Body. Research Paper No. 267 DBR/NRCC Ottawa. July 1965 (NRC 8600)

71 Ford, J.K. "Humidity Measurement and Modelling in a Residential Attic, Moisture Migration in Buildings ASTM STP 779. M. Lieff and H.R. Trechsel, Eds. American Society for Testing and Materials, 1982, pp. 160-190.

72 Forest Products Laboratory Wood Handbook: Wood as an Engineering Material, Forest Service, U.S. Department of Agriculture, 1974.

73 Garden, G.K. Rain Penetration and Its Control, Canadian Building Digest 40, DBR/NRCC Ottawa, April 1963.

74 Garden, G.K. Control of Air Leakage is Important, Canadian Building Digest 72, DBR/NRCC Ottawa, December 1965.

75 Gavin, Patrick M. Moisture Migration in Walls: A Summary of Current Understanding. Paper presented at recent BTECC Moisture Workshop. Sept. 1984 (sent by author) Research and Development Division, Owens-Corning Fibreglas Corporation, Technical Center, Granville, Ohio 43023.

76 Globus, A.M. and M.A. Kaganov "A Portable Device and Probe for the Measurement of Moisture Content and Temperature of Capillary Porous Materials". RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.

77 Granum, Hans — "Evaporation of Moisture from Wall Surfaces" RILEM/CIB Symposium on Moisture Problems in Buildings. Otaniemi, Finland, August 16-19, 1965.

78 Gravelle, Paul N. — Newfoundland Humidity Control Experiment. Prepared for the Project Implementation Division, Canada Mortgage and Housing Corporation, St. John's, Nfld.: Paul N. Gravelle and Associates Ltd., 1983.

79 Gray, William G. — "A Derivation of the Equations for Multi-Phase Transport, Chemical Engineering Science, Vol. 30, 00. 229-233, 1975.

80 Groom, Martha and Gautam S. Dutt — Moisture Problems in Buildings (Draft), A Bibliography prepared for the Building Thermal Envelope Coordinating Council, Center for Energy and Environmental Studies, Princeton University, Princeton, N.J.

81 Groot, S.R. de — "On the Thermodynamics of Irreverisble Heat and Mass Transfer", Int. J. Heat Mas Transfer, Vol. 4, pp. 63-70, 1961.

82 Gummerson, R.J., C. Hall and W.D. Hoff — "Water Movement in Porous Building Materials - II. Hydraulic suction and sorptivity of brick and other masonry materials", Building and Environment, Vo. 15, 1980, pp 101-108.

83 Gupta, J.P. and S.W. Churchill — "Moisture Transfer in Porous Medium Under a Temperature Gradient" Conservation in Heating, Cooling and Ventilating Buildings, Vol. 1, Hemisphere Publishing Corp., 1978.

84 Hall, C. — "Water Movement in Porous Building Materials - I. Unsaturated Flow Theory and Its Applications" Building and Environment, Vol. 12, 1977, pp. 117-125.

85 Hall, C. — "Water Movement in Porous Building Materials - IV. The Initial Surface Absorption and the Sorptivity". Building and Environment, Vol. 16, 1981, pp. 201-207.

86 Hall, C., W.D. Hoff and M.R. Nixon — "Water Movement in Porous Building Materials - VI. Evaporation and Drying in Brick and Block Materials". Building and Environment, Vol. 19, No. 1, pp. 13 - 20, 1984.

87 Hall, Christopher and A.N. Kalimeris — "Water Movement in Porous Building Materials - V. Absorption and Shedding of Rain by Building Surfaces", Building and Environment, Vol. 17, No. 4, 1982.

88 Handegord, G.O. — "Air Leakage, Ventilation and Moisture Control in Buildings", Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Ed., American Society for Testing and Materials, 1982, pp. 223-233.

89 Hansen, A.T. — Moisture Problems in Houses, Canadian Building Digest 23, DBR/NRCC, May 1984.

90 Harmathy, T.Z. — Moisture and Heat Transport with Particular Reference to Concrete, Research Paper No. 494, DBR/NRCC. Oct. 1971 (NRCC 12143).

91 Harmathy, T.Z. — Moisture Sorption of Building Materials, Technical Paper No. 242 of Division of Building Research, National Research Council of Canada, Ottawa, March 1967. (NRC 9492).

92 Harmathy, T.Z. — Simultaneous Moisture and Heat Transfer in Porous Systems with Particular Reference to Drying. Research Paper No. 407 of Division of Building Research, National Research Council of Canada, Ottawa. July 1969 (NRC 10854).

93 Hedlin, C.P. — Effect of Moisture on Thermal Resistance of Some Insulations in a Flat Roof Under Field-Type Conditions, DBR Paper No. 1109. Ottawa: DBR, NRCC. 1983.

94 Hedlin, Charles — Some Design Characteristics of Insulation in Flat Roofs Related to Temperature and Moisture. Proceedings of the 5th Conference on Roofing Technology, April 19 - 20, 1979.

95 Hens, H. and F. Vaes — "The Influence of Air Leakage on the Condensation Behaviour of Lighweight Roofs", Air Infiltration Review, Vol. 6, No. 1, Nov. 1984.

96 Huang, C.L.D. "Multi-Phase Moisture Transfer in Porous Media Subjected to Temperature Gradient", International Journal of Heat and Mass Transfer, Vol. 22, pp. 1295 - 1307, 1979.

97 Hutcheon, N.B. Requirements for Exterior Walls, Canadian Building Digest 48, DBR/NRCC, Ottawa, Dec. 1963.

98 Hutcheon, N.B. Humidified Buildings, Canadian Building Digest 42, DBR/NRCC Ottawa, June 1963.

99 Hutcheon, N.B. Humidity in Canadian Buildings, Canadian Building Digest 1, DBR/NRCC Ottawa, Jan. 1960.

100 Hutcheon, N.B. Control of Water Vapour in Dwellings, Technical Paper No. 19, Division of Building Research, National Research Council Canada, June 1954 (NRC 3343).

101 Hutcheon, N.B. Stability and Durability of Masonry Materials, Technical Paper No. 29, Division of Building Research, National Research Council Canada, Ottawa, October 1955 (NRC 3753).

102 Hutcheon, Neil B., Handegord, Gustau O.P. Building Science for a Cold Climate, John Wiley and Sons, 1983.

103 Hutcheon, N.B. and Handegord, G.O. Evolution of the Insulated Wood Frame Wall in Canada. DBR Paper No. 946. Ottawa: Division of Building Research, National Research Council of Canada, 1980.

104 Hutcheon, N.B. Vapour Problems in Thermal Insulation. Technical Paper No. 55 DBR/NRCC Ottawa, Oct. 1958 (NRC 4920).

105 Hutcheon, N.B. Combined Heat and Moisture Flow Philosophy and Review of a Canadian Research Program. Research Paper No. 119 DBR/NRCC, Ottawa. Feb. 1961.

106 Hutcheon, N.B. and J.H. Jenkins Some Basic Characteristics of Wood. Canadian Building Digest 85, DBR/NRCC, Jan. 1967.

107 Hutcheon, N.B. and J.H. Jenkins Some Implications of the Properties of Wood. Canadian Building Digest 86, DBR/NRCC, Feb. 1967.

108	Isaksen, Trygve	"Rain Penetration in Joints. Influence of Dimensions and Shape of Joints on Rain Penetration". RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.
109	Ishikawa, Hirozo	"An Experiment on Mechanism of Rain Penetration through Horizontal Joints in Walls", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, Sept. 1974.
110	Johansson, C.H., Persson, G.	Moisture Absorption Curves for Building Materials (Swedish) NRCC TT 747, 1958.
111	Johnson, R.J.	"Residential Moisture Conditions - Facts and Experience" Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds. American Soceity for Testing and Materials, 1982, pp. 234-240.
112	Joy, F.A. and A.G. Wilson	Standardization of the Dish Method for Measuring Water Vapor Transmission, Research Paper No. 279, Building Research Division, National Research Council of Canada, January 1966 (NRC 8838)
113	Kays, W.M. and M.E. Crawfod	Convective Heat and Mass Transfer, McGraw-Hill Book Company, 1980.
114	Kelso, R.M.	"Water Vapor Flow and High Thermal Resistance Insulation Systems for Metal Buildings", Thermal Insulation, Materials and Systems for Energy Conservation in the '80's, ASTM STP 789, 1983, pp. 651 - 660.
115	Kent, A.D., G.O. Handegord, D.R. Robson	"A Study of Humidity Variations in Canadian Houses", ASHRAE Transactions, Vol. 72, Part 1, 1966.
116	Kiessl, K. and K. Gertis	Feuchtetransport in Baustoffen. (A literature review of the quantitative evaluation of moisture migration phenomena). Universitat Essen Gesamthochschule, Forschungsberichte Aus Dem Fachbereich Bauwesen 13, 1980.
117	Kohonen, R.	"Transient Analysis of the Thermal and Moisture Physical Behaviour of Building Constructions. Building and Environment, Vol. 19, No. 1, pp. 1 - 11, 1984.

118	Kohonen, Riejo. A.	"A Method to Analyze the Transient Hygrothermal Behaviour of Building Materials and Components". Technical Research Center of Finland, Publications 21, Oct. 6 1984 (also:Thesis for Doctor of Technology Helsinki University of Technology, Otaniemi, Finland).
119	Kooi, J. Van der	Moisture Transport in Cellular Concrete Roofs, Ph.D., Thesis, Delft, Eindhoven, 1971.
120	Korsgaord, Vagn and Mogens R. Byberg	"Driving Rain Tests with Cavity Filled Brick Walls", RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.
121	Kreuger, Carl-Henrik	Moisture Problems in Single Family Dwellings. Translated by J. Timusk. Don Mills, Ont.: Marshall Macklin Monaghan Ltd., 1982
122	Kumaran, M.K. and M. Bomberg	"A Gamma-Spectrometer for Determination of Density Distribution and Moisture Distribution in Building Materials", Moisture and Humidity 1985, Proceedings of the 1985 International Symposium on Moisture and Humidity, April 15 - 18, 1985.
123	Kusuda, Tamami	"Measurement of Moisture Control for Building Interior Surfaces", Moisture and Humidity 1985, Proceedings of the 1985 International Symposium on Moisture and Humidity, Washington, D.C., April 15 - 18, 1985.
124	Kusuda, Tamani	"Calculation of the Temperature of a Flat-Plate Wet Surface under Adiabatic Conditions with Respect to the Lewis Relation", Proceedings of the 1963 Int. Symposium on Humidity and Moisture Vol. 1 R.E. Ruskin (ed.) Reinhold Publishing Corp., 1965.
125	Kusuda, T. and K. Ishii	Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada, Building Science Series 96, National Bureau of Standards, April 1977.
126	Kuzmak, J.M. and P.J. Sereda	The Mechanism by Which Water Moves Through a Porous Material Subjected to a Temperature Gradient: I Introduction of a Vapor Gap into a Saturated System, Research Paper No. 47, DBR/NRCC, Jan. 1958 (NRC 4491).

127	Lacy, R.E.	"Driving Rain Maps and the Onslaught of Rain on Buildings". RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.
128	Lacy, R.E. and H.C. Shelland	"An Index of Driving Rain" Met.Mag., Lond., 91, 1962, pp. 177 - 184.
129	Langlais, C. and S. Klansfeld	"Heat and Mass Transfer in Fibrous Insulations", Journal of Thermal Insulation, Vol. 8, July 1984
130	Latouche, Marcel	Report on Relative Humidity in a Double-Wall System. Fredericton, N.B., New Brunswick Housing Corporation, 1983.
131	Latta, J.K.	Walls, Windows and Roofs, for the Canadian Climate: A Summary of the Current Basis for Selection and Design, Special Technical Publication No. 1, Division of Building Research, National Research Council Canada, Ottawa, Oct. 1973.
132	Latta, J.K.	Water and Building Materials, Canadian Building Digest 30, DBR/NRCC Ottawa, June 1962.
133	Latta, J.K.	Vapour Barriers: What are They? Are They Effective? Canadian Building Digest 175, DBR/NRCC Ottawa, March 1976.
134	Latta, J.K. and R.K. Beach	Vapour Diffusion and Condensation. Canadian Building Digest 57, DBR/NRCC, Sept. 1964.
135	Luck, James R. and L.W. Nelson	"The Variation of Infiltration Rate with Relative Humidity in a Frame Building" ASHRAE Trans. 83, pt. 1 pp. 718 - 729, 1977.
136	Luft, F.J.	"A Study of Moisture Migration and Accumulation in Residential Stud Walls" in Thermal Performance of the Exterior Envelopes of Buildings II: Proceedings of the ASHRAE/DOE Conference, Dec. 6 - 9, 1982, Dunes Hotel, Las Vegas, Nevada, pp. 1078 - 1089. ASHRAE SP 38. Atlanta, GA: ASHRAE, 1983.
137	Luikov, A.V.	"Systems of Differential Equations of Heat and Mass Transfer in Capillary Porous Bodies", International Journal of Heat and Mass Transfer, Vol. 18, pp. 1-14, 1975.

138	Luikov, A.V.	Analytical Heat Diffusion Theory, Academic Press, 1968.
139	Luikov, A.V.	Heat and Mass Transfer in Capillary-Porous Bodies, Pergamon Press, 1966.
140	Marshall Macklin Monaghan Ltd.	Moisture Induced Problems in NHA Housing, Part 1: Analysis of Field Survey Results and Projections of Future Problems (J.H. Van Poorten) for Canada Mortgage and Housing Corporation, 1983.
141	Marshall, Macklin and Monaghan Ltd.	Moisture Induced Problems in NHA Housing Part 2: Literature Review and Research (J. Timusk) for Canada Mortgage and Housing Corp., 1983
142	Marshall, Macklin and Mongahan Ltd.	Moisture Induced Problems in NHA Housing Part 3: Applicable Moisture Reduction Techniques for Newfoundland (J. Melchers) for Canada Mortgage and Housing Corporation, 1983.
143	Matsumoto, Mamoru	"Simulataneous Heat and Moisture Transfer in Porous Wall and Analysis of Internal Condensation", C.J. Hoogendoorn and N.H. Afgan (Ed) Vol. 1, Hemisphere Publishing Corp., 1978.
144	Mayer, E. and H. Kuenzel	Test Results Concerning the Ventilation of the Air Space Behind Siding Using Small Scale Elements, 1981.
145	Mei, Harry T. and K.H. Yang	"A Study of Condensation in Walls in Warm Humid Climates, Moisture and Humidity 1985, Proceedings of the 1985 International Symposium on Moisture and Humidity, April 15 - 18, 1985.
146	Merte, H. and C. Yamali	"Profile and Departure Size of Condensation Drops on Vertical Surfaces", Warme-und Stoffubertragung 17, pp. 171-180.
147	Mertin, W.	"Method of Measuring the Distribution of Moisture in Concrete and Reinforced Concrete Structures". RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.
148	Miller, J.D.	"Development of Validation of a Moisture Mass Balance Model for Predicting Residential Cooling Energy Consumption" ASHRAE Transactions 90, pt. 2 (1984): 275 - 293.

149 Miller, L.M. "Some Comparative Observations on and Aspects of Thermal Insulation, Condensation and Vapour Transmission" The Heating and Ventilating Engineer and Journal of Air Conditioning. Vol. 46, No. 542, Sept. 1972.

150 Miller, R.G. and W.P. Goss Moisture Effects in Insulation Systems. Jim Walter Research Corp. 1985 (obtained from author - preliminary)

151 Minnen, J. van and B.H. Vos Determination of Water Content, Water Distribution and Heat Resistance of Walls, I. Report Nr. II - 4/23 N5, Institute T.N.O. for Building Materials and Building Structures I.B.B.C. Delft. 1965.

152 Minnen, J. van and B.H. Vos Determination of Water Content, Water Distribution and Heat Resistance of Walls II. Report Nr. II - 9/23 N5, Institute T.N.O. for Building Materials and Building Structures, I.B.B.C. Delft. 1965.

153 Modi, Debendra K. and Steve M. Benner Moisture Gain of Spray-Applied Insulations and Its Effect on Effective Thermal Conductivity - Part I. Drexel University, Philadelphia, P.A., March 1985 (internal correspondence).

154 Morrison Hershfield Ltd. and Scanada Consultants Ltd. Development and Testing of New Assemblies for Moisture Control. Proposal by P.A. Irwin, G.D. Schuyler, R.E. Platts, Aug. 1984.

155 Motakef, Shahryar and Maher A. El-Masri "Liquid Diffusion in Fibrous Insulation", ASME Paper 83-WA/HT-60, 1983.

156 Mullins, E.J. and T.S. McKnight Canadian Woods: Their Properties and Uses, University of Toronto Press, Toronto, 1981.

157 Musgrave, D.S. "Moisture Transport in a Metal Building Roof Insulation System", Moisture Migration in Buildings, ASTM STP 779. M. Lieff and H.R. Trechsel, Eds., American Soceity for Testing and Materials, 1982, pp. 54-64.

158 National Research Council of Canada — Exterior Walls: Understanding the Problems; Building Science Forum '82, Proceedings No. 6., Division of Building Research, National Research Council Canada, Ottawa, April, 1983 (NRCC 21203).

159 National Research Council of Canada — Humidity, Condensation and Ventilation in Houses, Building Science Insight '83, Proceedings No. 7, Division of Building Research, National Research Council of Canada, Ottawa, May 1984 (NRC 23293).

160 Newman, A.J. — "The Independant Core Method - A New Technique for the Determination of Moisture Content", Building Science. Vol. 9, pp. 309 - 313, 1974.

161 Ogniewicz, Y. and C.L. Tien — "Analysis of Condensation in Porous Insulation" International Jounral of Heat and Mass Transfer, Vol. 24. pp. 421 - 429, 1981.

162 Onysko, D. — Monitoring the Moisture and Thermal Performance to Two Test Walls Exposed to Outside Conditions. Ottawa: Eastern Laboratory, Forintek Canada Corp. 1984.

163 Onysko, D.M. — Interstitial Condensation in Walls: A Problem Analysis. Forintek Canada Corp., Eastern Laboratory, March 1985.

164 Onysko, D.M. — Moisture Management in Residential Construction: Report of a Study Tour to Norway and Sweden Project No. 55 - 43-034. Ottawa: Eastern Laboratory, Forintek Canada Corp., 1984.

165 Palosaari, S.M. and A.R.H. Cornish — "The Steady State Effective Thermal Conductivity of Closed Wetter Porous Systems", Acta Polytechnica Scandinavica, Series No. 125, Helsinki, 1975, pp. 3-34.

166 Palosaari, S.M. and A.R.H. Cornish — "An Approximate Method for the Prediction of the Effective Thermal Conductivity of Wetted Porous Materials", Acta Polytechnica Scandinavica, Series No. 126, Helsinki, 1975, pp. 3-24.

167 Palosaari, S.M. and A.R.H. Cornish — "A Method of the Prediction of the Evapouration Thermal Gradient Coefficient in Wetted Porous Materials, "Acta Polytechnica Scandinavica, Series No, 127, Helsinki, 1975, pp. 3-18.

168 Palosaari, S.M. and A.R.H. Cornish — "A Method of the Prediction of the Capillary Thermal Gradient Coefficient in Wetted Porous Materials, "Acta Polytechnica Scandinavica, Series No, 128, Helsinki, 1975, pp. 3-38.

169 Palosaari, S.M. and A.R.H. Cornish — "Capillary Pressure as a Function of Moisture Content in Porous Materials", Acta Polytechnica Scandinavica, Series No. 129, Helsinki, 1975, pp. 3-31.

170 Perrin, B., J.C. Foures et R. Javelas — "Determination du Coefficient de Diffusion Isotherme de l'Humidite dans des Materiaux de Construction", Materials and Structures Vol. 16, no. 91, Jan. Feb. 1983.

171 Perrine, E.L. — "Moisture Accumulation and Movements in Roof Insulation" Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds. American Society for Testing and Materials, 1982, pp. 41-53.

172 Pihlajavaara, S.E. — "Estimation of the Drying of Concrete", RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.

173 Pingry, J.R. and R.B. Engdahl — "Surface-moisture phenomena under Icing Conditions", Proceedings of the 1963 International Symposium on Humidity and Moisture, Vol. 3 A. Wexler et al (ed.) Rinehold Publishing Corp., 1965.

174 Platts, Robert E. — "Wet Walls in Canadian Houses: Problems, Solutions, Policy", 2nd CSCS Conference on Building Science and Technology, Waterloo, Ont. 1983.

175 Plumb, O.A., Craig A. Spolek and Bradley A. Olmstead — "Heat and Mass Transfer in Wood During Drying", International Journal of Heat and Mass Transfer (soon to be published)

176 Quirouette, R.L. — Water Vapour as a Tracer Gas for Measuring Air Change Rates in Houses. DBR Paper No. 1085, Ottawa: DBR/NRCC, 1982.

177 Rodgers, Golinn G., Graham Poots, John K. Page, William M. Pickering — "Rain Impactaction on a Slab Type Building A Theoretical Approach", 2nd RILEM/CIB on Symposium on Moisture Problems in Buildings, Rotterdam, 1972.

Roofing Technology, Proceedings of the 5th Conference on -. April 19 - 20, 1979 - NBS.

178 Rodwell, D.F.G. "Water Vapour Diffusion Through Plasterboard Wall Linings and Damaged Vapour Barriers", Building Services Engineer, pp. 69-74, Vol. 45, August 1977.

179 Rousseau, Madeleine Z. "Sources of Moisture and Its Migration through the Building Enclosure", ASTM Standardization News, Nov. 1984, pp. 35 - 37.

180 Sandberg, Per I. "Driving Rain Distribution over an Infinitely Long High Building: Computer Calculations", in 2nd RILEM/CIB Symposium on Moisture Problems in Buildings, Rotterdam, Sept. 1974.

181 Sandberg, Per I. "The Effect of Boundary Conditions on Moisture Content in Building Elements", 2nd International CIB/RILEM Symposium on Moisture Problems in Buildings, Rotterdam, Sept. 1974.

182 Sawars, John W. Condensation in the Home: Where, Why and What to Do About It, Canada Mortgage and Housing Corporation, 1984.

183 Scanada Consultants Ltd. A Survey of Moisture Problems in New Housing, For Technical Research Division, Canada Mortgage and Housing Corporation, May 1980.

184 Scanada Consultants Ltd. Survey of Moisture Problems in Thermally Upgraded Existing Houses, Prepared for the Division of Building Research, National Research Council, Canada, Contract 078-042-8-4452, Sept. 1979.

185 Scott, D.L. Rain Leakage in Wood Frame Walls: Two Case Histories. Building Research Note No. 210. Ottawa: DBR/NRCC, 1984.

186 Scott, D.L. Seasonal Moisture Variation in Wood Siding and Framing: A Case Study, Building Research Note No. 205, Division of Building Research, National Research Council Canada, Ottawa, Nov. 1983.

187 Sereda, P.J. and N.B. Hutcheon Moisture Equilibrium and Migration in Building Materials. Technical Paper No. 205 DBR/NRCC, Ottawa. Aug. 1965 (NRC 8651).

188 Sereda, P.J. and R.F. Feldman — Wetting and Drying of Porous Materials. Canadian Building Digest 130, DBR/NRCC, Oct., 1970.

189 Shaw, C.Y. — The Effect of Mechanical Ventilation of the Air Leakage Characteristics of a Two-Storey House, National Research Council of Canada, Division of Building Research, Research Note 204, July 1983.

190 Sherman, M.H., J.W. Adams and R.C. Sonderegger — "Simplified Thermal Parameters: A Model of the Dynamic Performance of Walls", Thermal Insulation, Materials and Systems for Energy Conservation in the '80's, ASTM STP 789, 1983, pp. 355 - 372.

191 Sherwood, G.E. — Condensation Potential in High Thermal Performance Walls - Cold Winter Climate Research Paper FPL 433. Madison, Wis.: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, 1983. (NTIS AD-A129 452).

192 Sherwood, G.E. and C.C. Peters — Moisture Conditions in Walls and Ceilings of a Simulated Older Home During Winter. USDA Forest Service Research Paper FPL 290, Forest Products Lab., Madison, Wis. 1977.

193 Shuman, E.C. — "Some Effects of Moisture Migration and Persistence in Building Materials", Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds., American Society for Testing and Materials, 1982, pp. 65-79.

194 Slattery, John C. — Momentum, Energy and Mass Transfer in Continua, McGraw-Hill Book Company, 1972.

195 Stephenson, D.G. — Heat Transfer at Building Surfaces, Canadian Building Digest 52, DBR/NRCC, April 1964.

196 Stewart, M.B. — "Annual Cycle Moisture Analysis", ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelopes of Buildings, ASHRAE, Inc. pp. 887 - 897, 1981.

197 Stewart, M.B. — "An Experimental Approach to the Study of Moisture Dynamics in Walls" Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Treshsel, eds., American Society for Testing and Materials, 1982, pp. 92 - 101.

198 TES Limited — Demonstration of Moisture Control by Venting (Casselman). Prepared for Product Implementation Division, Canada Mortgage and Housing Corporation, Ottawa, 1982.

199 TES Limited — Instrumentation Report Newfoundland Humidity Control Experiment TES Report C446. Prepared for CMHC, Ottawa, 1982.

200 TES Limited — Monitoring Kit for Neutral Pressure Plane and Humidity Levels Prepared for Canada Mortgage and Housing Corporation. Ottawa, 1982.

201 TES Limited — Report on Data Acquisition System Proposed for Humidity Measurement in Houses. TES Report C438. Prepared for Canada Mortgage and Housing Corporation. Ottawa, 1982.

202 Tamura, G.T. and A.G. Wilson — Air Leakage and Pressure Measurements on Two Occupied Houses, Research Paper No. 207, DBR/NRCC, Dec. 1963.

203 Teesdale, L.V. — Comparative Resistance to Vapor Transmission of Various Building Materials, Presented at 49th Annual Meeting of the American Society of Heating and Ventilating Engineers, Cincinnati, Ohio, 1943.

204 TenWolde, A. — "Steady-State One-Dimensional Water Vapour Movement by Diffusion and Convection in a Multilayered Wall". ASHRAE Transactions, Vol. 91, Part 1, 1985.

205 TenWolde, A. — The Kieper and Moist Wall Moisture Analysis Methods for Walls. Obtained from the author.

206 Thermoscan Limited — Moisture Induced Structural Damage in NLHC Units. St. John's, Newfoundland, 1982.

207 Thomas, W.C., G.P. Bal and R.J. Onega — "Heat and Moisture Transfer in a Glass Fiber Roof-Insulating Material", Thermal Insulation, Materials and Systems for Energy Conservation in the '80's, ASTM STP 789, pp. 582 - 601

208 Tibbetts, D.C. and D.R. Robson — Wetting and Drying of Small Wood Panels Building Research Note No. 78, DBR/NRCC, Aug. 1971.

209	Timusk. J. and H. Doshi	Effect of Insulating Sheathing on Heat and Moisture Flow
210	Timusk, J., and J.K. Lischoff	"Moisture and Thermal Aspects of Insulated Sheathings", 2nd CSCE Conference on Building Science and Technology, Waterloo, Ont., 1983.
211	Tobiasson, Wayne and John Ricard	Moisture Gain and Its Thermal Consequence for Common Roof Insulations. Proceedings of the 5th Conference on Roofing Technology, April 19 - 20, 1979.
212	Trechsel, H.R., Achenbach, P.R. and Launey, S.J.	"Moisture Control in Building Wall Retrofit", Moisture Migration in Buildings ASTM STP 779, M. Lieff and H.R. Trechsel, Eds., American Society for Testing and Materials, 1982, pp. 148-159.
213	Trechsel, H.R. and P. Reece Achenbach	Field Study of Moisture Problems in Exterior Walls of Family Housing Units at Naval Air Station Pensacola, Florida H.R. Trechsel Associations, Germantown, MD, CR 84.022 Naval Civil Engineering Laboratory Feb. 1984 (NIIS AD A1 39637).
214	Trechsel, Heinz R.	"Moisture in Buildings: An Overview", ASTM Standardization News, Nov. 1984, pp. 22 - 23.
215	Trethowan, H.A.	Condensation in Cavities of Building Structures Wellington, Building Research Association of New Zealand, Report R5, 1977.
216	Trethowan, H.A.	Drying and Condensation in Walls: Computer Simulation, BRANZ Report R14, Wellington, N.Z., 1975.
217	Trethowan, H.A.	Theory of Condensation and Mildew. Building Research Association of New Zealand, Report CR3, 1972.
218	Trethowan, H.A. and E.F. Hubbard	Water Vapour Diffusion Resistance of New Zealand Building Materials Building Research Association of New Zealand, Report R2, April 1975.
219	Tsongas, George A., F. Glen Odell, and James C. Thompson	"A Field Study of Moisture Damage in Walls Insulated Without a Vapour Barrier". Paper presented at Solar 79 Northwest Conference, Seattle, Washington. August 1979.

220 Tveit, Annanias — Measurements of Moisture Sorption and Moisture Permeability of Porous Materials, Norwegian Building Research Institute, Rapport 45, 1966.

221 Tveit, Annanias — "Factors Affecting the Moisture Permeability of Porous Materials and the Calculation of Moisture Transport and Condensation Hazard in Building Structures", RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August, 1965.

222 Uyttenbroek, Ir. J. and Ing. G. Carpentier — "Criteria for the Avoidance of Mould Growth in Dwellings", Moisture and Humidity 1985, Proceedings of the 1985 International Symposium on Moisture and Humidity, Washington, D.C., April 15 - 18, 1985.

223 Verschoor, Jack D. — "Moisture Migration in an Insulated Residential Wall Structure" ASHRAE Journal, Research Note 49, November 1985.

224 Vos, B.H. — Condensation in Structures. Report No. BI-67-33, Institute TNO for Building Materials and Building Structures, IBBC. Delft, March 1967

225 Vos, B.H. — "Measurements of Moisture Content in Building Structures in Situ", RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.

226 Vos, B.H. — "Theoretical and Experimental Investigations into the Thermo-hygric Behaviour of a Cavity Wall", RILEM/CIB Symposium on Moisture Problems in Buildings, Otaniemi, Finland, August 16-19, 1965.

227 Vos, B.H. — Thermal and Hygric Aspects of Cavity Structures Part I Thermal Aspects of Cavity Structures Report No. BI-65-61, Institute TNO for Building Materials and Building Structures. IBBC, Delft, Dec. 1965.

228 Vos, B.H. — Thermal and Hygric Aspects of Cavity Structures, Part II Hygric Aspects of Normal Cavity Walls (Theory). Report No. BI-66-4-E, Institute TNO for Building Materials and Building Structures IBBC, Delft, June 1966.

229 Vos, B.H. — Ventilation in Flat Roofs Report No. BI65-13 Institute TNO for Building Materials and Building Structures, IBBC, Delft, Feb. 1965.

230 Wang, F.S. — "Comparative Studies of Vapour Condensation Potentials in Wood Framed Walls" in Thermal Performance of the Exterior Envelopes of Buildings: Proceedings of ASHRAE/DOW-ORNL Conference: Dec. 3 - 5, 1979, Orlando Hyatt Hotel, Kissimmee, Florida, pp. 836 - 846 ASHRAE SP 28. NY: ASHRAE, 1981.

231 Wetterman, T.A. — "Control of Moisture Migration in Light Frame Walls", Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds., American Society for Testing and Materials, 1982, pp. 102-109.

232 White, Jim H. — Ventilation Compliance Tests for Houses, APCA Meeting, San Francisco, 84-32.2, 1984.

233 White, Jim H. — Ventilation for Humidity Control: A Research Report. Ottawa: Research Division, Canada Mortgage and Housing Corporation, 1984.

234 White, Jim H. and Rick L. Quirouette — "Condensation in Canadian Homes"

235 White, Jim H., Paul Skvor — "The House as a Moisture Source", APCA Speciality Conference on "Indoor Air Quality in Cold Climates: Hazards and Abatement Measures", Ottawa, 1985.

236 Whiting, D. — Assessment of Potential Techniques for In-site, Real Time Moisture Measurements in Building Envelope Systems - A Literature Survey. Prepared by Portland Cement Association, Skokie, Illinois 1983. (ORNL/SUB-83-40122/1 E 1.99:DF34 007799)

237 Wilkes, Kenneth E. — "Thermophysical Properties Data Base Activities at Owens-Corning Fiberglas" ASHRAE/DOE Conference on the Thermal Performance of Exterior Envelopes of Buildings, ASHRAE SP28, pp. 662 - 677, 1981.

238 Wilson, A.G. Condensation in Insulated Masonry Walls in Summer, Technical Paper No. 226, Division of Building Research National Research Council Canada, Ottawa, July 1966 (NRC 9130).

239 Wilson, A.G. Condensation on Inside Window Surfaces, Canadian Building Digest 4, DBR/NRCC Ottawa, April 1960.

240 Wilson, A.G. and G.K. Garden Moisture Accumulation in Walls Due to Air Leakage, Technical Paper No. 227, Division of Building Research, National Research Council of Canada, July 1966 (NRC 9131).

241 Wilson, Forrest "Building Diagnostics" Architectural Technology, Winter, 1985.

242 Zarling, J.P., Rice, E. and Swanson, K.C. "Moisture Problems in Buildings in the Subarctic", Moisture Migration in Buildings, ASTM STP 779, M. Lieff and H.R. Trechsel, Eds., American Society for Testing and Materials, 1982, pp. 262-274.

APPENDIX B

PRELIMINARY ANALYSIS

B.1 Lumped Parameter Airspace Moisture Analysis

M.J. Cunningham (Reference 1) has developed a simple but useful analysis to study the moisture behavior of airspaces within structures which contain hygroscopic materials. In addition to the release of moisture from materials in the airspace, the model allows for convection and diffusion of vapour with other airspaces. It was modified slightly to account for evaporation from liquid water or saturated surfaces. Some results of the analysis will be summarized here.

The analysis involves the solution of two coupled first order differential equations, namely:

$$V_o \frac{d \rho_o}{d t} = A_m h \left(k m - \frac{\rho_o R T}{W}\right) + \sum_i \left[\frac{RT}{W} A_i h_i (\rho_i - \rho_o) + V_o (F_{io} \rho_i - F_{oi} \rho_o)\right] + A_s h_s \left(p_s - \frac{RT}{W} \rho_o\right) \quad (1)$$

$$V_m \frac{d m}{d t} = - A_m h \left(k m - \rho_o \frac{RT}{W}\right) \quad (2)$$

The variables are defined as follows:

- V_o - volume of airspace (m^3)
- ρ_o - density of water vapour in the airspace (kg m^{-3})
- t - time (s)
- A_m - area of the hygroscopic material exposed to the airspace (m^2)
- h - lumped vapour permeance (conductance) of hygroscopic material to airspace (kg m^{-2} s^{-1} Pa^{-1})
- k - proportionality constant linearizing the sorption curve of the hygroscopic material (m^2 s^{-2})

R - gas constant (J K^{-1} $Kmole^{-1}$)

T - averaged temperature (K)

W - molecular weight of water (kg)

A_i - effective surface area for flux of vapour to or from airspace i (m^2)

h_i - effective permeance between airspace and air space i (kg m^{-2} s^{-1} Pa^{-1})

ρ_i - density of water vapour in airspace i (kg m^{-3})

F_{io} - air change rate from region i to the airspace (s^{-1})

F_{oi} - air change rate from the airspace to region i (s^{-1})

A_s - effective area of liquid water in airspace (m^2)

h_s - permeance (air film) from liquid water to airspace (kg m^{-2} s^{-1} Pa^{-1})

p_s - saturation vapour pressure (Pa)

V_m - volume of hygroscopic material (m^3)

m - moisture content of hygroscopic material (kg m^{-3})

Equation (1) describes the behavior of the airspace vapour density, ρ_o, while Equation (2) describes the time dependence of the moisture density, m, within the hygroscopic material in the airspace. In equation (1), the change in vapour density depends on three vapour flow components. The first expression on the right hand side is the net flow between the airspace and the hygroscopic material. The term within the summation is the moisture exchange between the airspace and other airspaces. The third term is the exchange between a water surface and the airspace. The moisture exchange between the airspace and other airspaces is made up of a diffusion component (the first term in square brackets) and an air leakage component (second item in square brackets).

It should be noted that a single average temperature is assumed and the external vapour densities are held constant. The moisture content of the material is in the pendular region with k representing the slope of the appropriate portion of the sorption isotherm of the material. A single lumped value of permeance between the hygroscopic material and the airspace is used with average values of moisture densities in the material and airspace.

The system of differential equations (1) and (2) has been solved. For the values of the variables found in wood-based structures the moisture density in the hygroscopic material is given by:

$$m = \left[(M_o - m_f)\, e^{-t/t_2} \right] + m_f \qquad (3)$$

where:

M_o - initial moisture density (kg m^{-3})
m_f - final moisture density (kg m^{-3})

$$m_f = \frac{t_o}{\kappa} \left[\sum_i \left[\left(\frac{RT}{WV_o} A_i h_i - F_{io} \right) \rho_i \right] + \frac{A_s h_s}{V_o} p_s \right] \qquad (4)$$

$$t_2 = \frac{t_o \nu}{\kappa} + t_m \qquad (5)$$

and

$$t_o^{-1} = \sum_i \left(\frac{RT}{W V_o} A_i h_i + F_{o\,i} \right) + \frac{RT}{W V_o} A_s h_s \qquad (6)$$

$$t_m = \frac{h k A_m}{V_m} \qquad (7)$$

$$\kappa = \frac{k\,W}{R\,T} \tag{8}$$

$$\nu = \frac{V_m}{V_o} \tag{9}$$

Time constant, t_m, is a measure of the response rate of the hygroscopic material to a change in the airspace vapour density while, t_o, represents the airspace response time to changes in the vapour density in other airspaces or to changes in the area of liquid water. Another time constant, t_1, represents the short time response of the vapour concentration in the airspace including the effect of the hygroscopic material

$$t_1 = \frac{t_o}{1 + (t_o\ \nu / t_m \kappa)} \tag{10}$$

The long time response of the airspace is tied to that of the hygroscopic material and has a time constant of t_2.

Five sample cases have been worked through to demonstrate the Cunningham model and to gain an idea of the range of time constants which might be expected in a real wall. Representative values of material properties were chosen from various sources including references (2-5). All values correspond to a temperature of 0°C and an exterior relative humidity of 50%. They, like the model, can only be considered adequate to give answers to within an order of magnitude. The cases are described below while Table B1 summarizes the important results.

Case 1 - Furring strips were used to provide a continuous airspace behind the siding layer with an average width of 2.5 cm. The wall is 3m high. An average airflow velocity of 0.1m/s is used and assumed to dominate any other leakage or diffusion. The hygroscopic material consists of the sheathing which is separated from the airspace by a layer of building paper. The siding material is not considered. No drying takes place to the interior of the wall.

The resulting time constants, t_1 and t_2, were determined to be 26s and 2.3 x 10^6s (27 days), respectively. The final vapour and moisture concentrations will naturally correspond to the humidity of the outdoor air.

Case 2 - The furring strips of Case 1 are removed and the siding nailed directly to the sheathing. It is assumed that no convection occurs. Vapour may diffuse through a 1mm wide x 25mm long gap between siding boards to the exterior.

The elimination of the flow of outdoor air behind the airspace results in a large increase in the long term time constant, t_2, to 790 days.

Case 3 - Case 1 is repeated but with the back surface of the siding layer covered with a film of liquid water. It is assumed that this film does not dry.

The time constants are reduced slightly but the equilibrium relative humidity in the airspace is raised to 87%.

Case 4 - Case 2 is repeated but with the back surface of the siding layer covered with a water film.

The time constant, t_2, is reduced significantly from Case 2, but the sheathing will end up very wet with an airspace relative humidity of 99%.

Case 5 - Case 1 is repeated but with the building paper removed.

The significant drop in the long term time constant from 27 to 5.8 days is illustrative of the role the building paper can play in preventing the sheathing from drying.

B.2 Lumped Parameter Thermal Analysis

To obtain a lumped parameter thermal analysis the moisture analysis developed by Cunningham was modified to treat heat transfer instead of moisture transfer. The differential equations corresponding to equations (1) and (2) are:

$$V_c \rho_c c_{pc} \frac{d T_c}{d t} = A_m h_m (T_m - T_c) + \sum_i \left[A_i h_i (T_i - T_c) + V_c \rho_c c_{pc} (F_{io} T_i - F_{oi} T_c) \right] \quad (11)$$

$$V_m \rho_m c_{pm} \frac{d T_m}{d t} = - A_m h_m (T_m - T_c) \quad (12)$$

where:

V_c - volume of the airspace (m^3)
ρ_c - air density in the airspace (kg m^{-3})
C_{pc} - specific heat of the air (J kg^{-1} K^{-1})
T_c - temperature of the airspace (^oK)
A_i - effective area for heat conduction between airspace and airspace i (m^2)

h_i - thermal conductance between airspace and airspace i ($J\ m^{-2}\ K$)

T_i - temperature of air-space i (K)

T_m - temperature of material (K)

F_{io} - air change rate from airspace i to airspace (s^{-1})

F_{oi} - air change rate from airspace to region i (s^{-1})

A_m - effective area for heat transfer from material to airspace (m^2)

h_m - heat conductance from material to airspace ($J\ m^{-2}K$)

V_m - volume of material in contact with airspace (m^3)

ρ_m - density of material ($kg\ m^{-3}$)

C_{pm} - specific heat of material ($J\ kg^{-1}\ K^{-1}$)

This thermal analysis is subject to limitations similar to those of the moisture analysis.

As in the moisture analysis, for the cases considered it turns out that the temperature of the material, T_c, decays exponentially to its final value.

$$T_c = (T_o - T_f)\, e^{-t/t_2} + T_f \tag{13}$$

where

$$t_2 = t_o\ \nu + t_m \tag{14}$$

$$t_o^{-1} = \sum_i \left[\frac{A_i\ h_i}{V_c\ \rho_c\ C_{pc}}\right] + F_{i\,o} \tag{15}$$

$$t_m^{-1} = \frac{A_m\ k}{V_m\ \rho_m\ C_{pc}} \tag{16}$$

$$\nu = \frac{V_m\ \rho_m\ C_{pm}}{V_c\ \rho_c\ C_{pc}} \tag{17}$$

$$T_f = t_o \left[\sum_i \left[\frac{A_i h_i}{V_c \rho_c C_{pc}} T_i + F_{io} T_i \right] \right] \qquad (18)$$

T_f represents the final temperature of the airspace and the material.

The short time response of the airspace with hygroscopic material in it is determined by the time constant t_1.

$$t_1 = \frac{t_o}{1 + (t_o \nu / t_m)} \qquad (19)$$

Two representative cases were chosen as examples:

Case 1 - This is the analog of the first case used to demonstrate the moisture analysis and represents an outer airspace formed by the use of furring strips. The material in the sheathing makes up the thermal mass (V_m) while the siding is given no thermal mass. Heat is transferred to the external air by conduction through the siding and by convection (air moves at .1 m s^{-1} in the airspace).

The calculated values of the time constants are:

$t_1 = 2.5s$, $t_2 = 4.6 \times 10^3 s$(77 min.)

As in the moisture case, the response of the airspace is very fast while the sheathing material has a time constant on the order of one hour.

Case 2 - Analogous to Case 2 in Section B.1, this example examines the case where no furring strips are used and heat is

transferred between the airspace and outside by conduction through the siding only. Again the thermal mass of the siding is not included.

The calculated time constants are:

$t_1 = 1.2s$, $t_2 = 2.8 \times 10^4$ s (7.7 hr)

Although still measured in hours, the longer time constant is significantly greater than that of the first case where furring strips were used.

B.3 Thermal Response of a Homogeneous Material

The general one-dimensional diffusion equation has the form:

$$\frac{\partial \Phi}{\partial t} = a^2 \frac{\partial^2 \phi}{\partial x^2} \qquad (20)$$

Depending on what ϕ and a^2 represent, (20) can be applied to heat or moisture transfer problems amongst others. For heat transfer ϕ represents temperature and:

$$a^2 = \frac{k}{\rho C_p} \qquad (21)$$

where

k - conductivity (W m^{-1} K^{-1})
ρ - density (kg m^{-3})
C_p - specific heat (J kg^{-1} K^{-1})

The solution of the diffusion equation takes many forms depending on the initial conditions and the domain in which the solution is to be found. Let us consider one dimensional heat conduction through the finite thickness (L) of a homogeneous material (siding, still airspace, sheathing, etc.). As a straight forward example, consider the case of the material initially at a uniform temperature of T_1 where the temperature at each boundary is changed to T_2 at time t = 0.

The solution may take the following form:

$$T = T_2 + (T_1 - T_2)\left[\frac{4}{\pi}\left[\sin\left(\frac{\pi x}{L}\right) e^{-(\pi a/L)^2 t} + \frac{1}{3}\sin\left(\frac{3\pi x}{L}\right) e^{-(3\pi a/L)^2 t} + \frac{1}{5}\sin\left(\frac{5\pi x}{L}\right) e^{-(5\pi a/L)^2 t} + \ldots\right]\right] \qquad (22)$$

At t = 0, the expression in brackets is the sine series representing a square wave of height 1 between 0 and L. For times greater than 0, the various terms decay exponentially with different time constants. The longest time constant, corresponding to the largest term is:

$$t_1 = \frac{L^2}{\pi^2 a^2} \qquad (23)$$

Because of symmetry, equation (22) can also be used to represent heat conduction in a material from 0 to L/2 where a temperature step is applied at x = 0 and no heat flow is allowed at x = L/2 (ie the material is backed by a perfect insulator).

Values of the longest time constant were calculated for various materials found in a wall. The material thickness was taken as 2cm. With a temperature step applied to one side of the material and the other side insulated the following values were obtained:

White Pine	1690s (28 min.)
Mineral Wool	338s (5.6 min.)
Still Air	8.7s

If the temperature step has been applied on both boundaries the time constants would be one quarter of those given.

B.4 Hygric Response of a Homogeneous Material

The diffusion equation discussed in B.3 may also be used to describe moisture diffusion in air or moisture movement in hygroscopic materials. For diffusion of one fluid through another

$$a^2 = D \qquad (24)$$

where D is the diffusion coefficient based on density (m^2/s)

Like Cunningham (Ref. 1), we may consider that equilibrium vapour pressure is the driving potential behind the movement of moisture in a hygroscopic material, i.e.

$$J_m = h \frac{d\,p(m)}{d\,x} \approx h\,k \frac{dm}{dx} \qquad (25)$$

J_m - moisture flux (kg m^{-2} s^{-1})
h - permeability (kg m^{-1} s^{-1} Pa^{-1})
p(m) - vapour pressure at equilibrium with moisture content m (Pa)
m - moisture content (kg m^{-3})
k - proportionality constant used to linearize the sorption isotherm (m^2 s^{-2})

In this case:

$$a^2 = hk \qquad (26)$$

The longest time constants were calculated for moisture movement into a 2cm wide channel of air and 2cm wide insulating board. It was assumed one side was impermeable. The values calculated were:

Insulating Board	3.2×10^5 s (3.8 days)
Air	7.4 s

B.5 Moisture and Temperature Distribution in the Airspace

The distribution of moisture density and temperature within the airspace will determine the distribution of moisture flux to or from the hygroscopic materials. To design the computer model, it is necessary to know whether the materials will dry out uniformly along the length of the airspace or not.

The differential equations to be solved for the moisture density and temperature in the air flowing between two plates Δx apart are:

$$\frac{\partial \rho}{\partial y} = \frac{2 J_m}{\bar{u}_v \Delta x} \qquad (27)$$

$$\frac{\partial \tau}{\partial y} = \frac{2 J_h}{\bar{u} \Delta x \rho_T C_p} \qquad (28)$$

The variables are defined as:

ρ = water vapour density (kg m^{-3})
J_m = moisture flux (kg m^{-2} s^{-1})
y = distance along channel (m)
Δx = width of channel (m)
$\bar{u}_v$ = average velocity of water vapour (m s^{-1})
$\bar{u}$ = average velocity of flow (m s^{-1})
J_h = heat flux (W m^{-2})
ρ_T = total air density (kg m^{-3})
C_p = specific heat (J kg^{-1} K^{-1})

The equations assume that conditions are the same on both plates. By neglecting the diffusion velocity u_v will be set equal to u.

In theory, equations (27) and (28) could be integrated after substitution of the equilibrium values of J_h and J_m. This can conveniently be done numerically but would be difficult analytically. The distribution may be solved by using the result that enthalpy is approximately the driving potential for simultaneous heat and moisture transfer (Ref. 2)

$$\frac{d E_c}{d y} = \frac{2 K_E (E_s - E_c)}{\bar{u} \Delta x \rho_A} \qquad (29)$$

where

E_c = the average specific enthalpy of the airspace air ($J\ kg^{-1}$)

E_s = the specific enthalpy of the air on the surface ($J\ kg^{-1}$)

K_E = h_m A_2 is the enthalpy transfer coefficient ($kg\ m^{-2}\ s^{-1}$)

ρ_A = density of dry air ($kg\ m^{-3}$)

By assuming surface conditions are constant along the length of the airspace equations (27), (28), and (29) may be integrated to yield.

$$\rho(y) - \rho_s = (\rho(o) - \rho_s)\, e^{-(y/L_\rho)} \tag{30}$$

$$T(y) - T_s = (T(o) - T_s)\, e^{-(y/L_T)} \tag{31}$$

$$E_c(y) - E_s = (E_c(o) - E_s)\, e^{-(y/L_E)} \tag{32}$$

L_ρ, L_T and L_E are the characteristic lengths for moisture density, temperature and specific enthalpy respectively. Using the Reynold's analogy based on the friction factor for laminar flow between parallel plates, the characteristic lengths were determined to be as follows:

$$L_\rho = \frac{\bar{u}\,\Delta x^2\,\rho_T}{1\,2\,\mu\,P_{AM}}\left(\frac{\mu}{\rho D}\right)^{2/3} \approx 4.4 \times 10^3\ m \tag{33}$$

$$L_T = \frac{\bar{u}\,\Delta x^2\,\rho_T}{1\,2\,\mu}\left(\frac{C_p\,\mu}{k}\right)^{2/3} \approx 4.9 \times 10^3\ m \tag{34}$$

$$L_E \approx L_\rho \tag{35}$$

Given that the time averaged airspace velocities may range from about .01 m s^{-1} to 1.0 m s^{-1} and the average airspace width could range from .6 cm to 2.5 cm the range of possible characteristic lengths is:

$L_\rho > 0.0016m$
$L_E < 2.7m$
$0.0018\ m < L_T < 3.1\ m$

The effect of the characteristic length on the drying performance of the wall is substantial. If one were to consider a wall with a very short characteristic length (i.e. 5 - 10 cm) then drying could only take place over approximately 15 cm. This would lead to the drying of spots near air entrances. As each spot gets dried, the dry spot would then begin to grow until the entire wall is dry.

This type of drying is fine, but if only average conditions are modelled in the wall, then an average moisture content in the sheathing of 20% could be caused by reasonably large wall areas at 10% and smaller areas at 50%. Thus when the average conditions indicate no danger of rotting, there may be localized areas where rotting can occur.

In the case of a very large characteristic length (i.e. 2m), drying takes place fairly uniformily over the entire wall. In this case average conditions describe the wall quite well.

B.6 Conclusions

Various conclusions important to the computer model design may be drawn from the preceding analyses and the accompanying examples. Some of these are listed below.

- At least limited ventilation is required to dry out wet walls in an acceptable time period if the siding is covered by a low permeance surface.

- Building paper can increase the drying time significantly for walls with a reasonable amount of ventilation to the exterior.

- Liquid moisture in an airspace can greatly reduce the degree to which the airspace walls will dry out, especially if the ventilation is limited.

- The moisture content and temperature of an airspace will generally respond in less than a minute to any change in conditions on the boundaries.

- The average moisture content of the hygroscopic material bordering on the airspace may take from a few days to years to dry depending on the resistance to vapour flow to the outside.

- The wall may take on the order of a few hours to respond to external temperature changes.

- Thermal response time constants for typical thicknesses of building materials (2 cm) are on the order of seconds for still air, minutes for insulation and an hour for wood.

- Hygric response time constants for typical thicknesses of

building materials are on the order of days for most fiber based hygroscopic materials and on the order of seconds for air spaces.

- The flow velocities averaged over a year to be expected in the outer airspace if furring strips are used are on the order of .1 m/s (0.1 to 1.0m s^{-1}).

- The characteristic length for properties in the airspace was estimated to be around 30cm but could vary from a few millimeters to a few meters. From this it is anticipated that the vertical spacing of the numerical model grid should be about the width of a siding board.

References

1) Cunningham, M.J. "A New Analytical Approach to the Long Term Behaviour of Moisture Concentrations in Building Airspaces - I. Non-Condensing Airspace", Building and Environment, Vol. 18, No. 3, pp. 109 - 116, 1983.

2) ASHRAE Handbook, 1985 Fundamentals, ASHRAE Inc., 1985.

3) Bolz, Ray E. and George L. Tuve (editors), Handbook of Tables for Applied Engineering Science, CRC Press, 1976.

4) TenWolde, A. "Steady - State One-Dimensional Water Vapour Movement by Diffusion and Convection in a Multilayered Wall". ASHRAE Transactions, Vol. 91, Part 1, 1985.

5) Johnson, C.H. and G. Persson. Moisture Absorption Curves for Building Materials, NRCC TT-747, 1953.

TABLE B1

RESULTS FROM LUMPED PARAMETER MOISTURE ANALYSIS

Case #	Time Constants t_1 (s)	t_2 (day)	Final Cavity Relative Humidity (%)
1	26	27	50
2	47	790	50
3	10	24	87
4	3.4	25	99
5	19	5.8	50

APPENDIX C

MATERIALS DATABASE

PROPERTIES OF MATERIALS COMMONLY FOUND IN WALLS 03-14-1986

RECORD NO. 1

NAME	: OUTDOOR AIR
DENSITY (Kg/m3)	: 1.21
HEAT CAPACITY (W.s)/(Kg.K)	: 1005
THERMAL RESISTIVITY ((m2.C)/W)/m	: 0
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.7E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 287.055
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 2

NAME	: WATER VAPOUR
DENSITY (Kg/m3)	: .598
HEAT CAPACITY (W.s)/(Kg.K)	: 2050
THERMAL RESISTIVITY ((m2.C)/W)/m	: 18.
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 0
GAS CONSTANT (Pa.m3)/(Kg.K)	: 461.52
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 3

NAME	: LIQUID WATER
DENSITY (Kg/m3)	: 998
HEAT CAPACITY (W.s)/(Kg.K)	: 4180
THERMAL RESISTIVITY ((m2.C)/W)/m	: 1.66
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 0
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 2

RECORD NO. 4

NAME	: INTERIOR AIR FILM
DENSITY (Kg/m3)	: 1.21
HEAT CAPACITY (W.s)/(Kg.K)	: 1005
THERMAL RESISTIVITY ((m2.C)/W)/m	: 20
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.7E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 287.055
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 5

NAME	: AIR SPACE
DENSITY (Kg/m3)	: 1.21
HEAT CAPACITY (W.s)/(Kg.K)	: 1005
THERMAL RESISTIVITY ((m2.C)/W)/m	: 5
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.7E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 287.055
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 6

NAME	: SHEATHING PAPER
DENSITY (Kg/m3)	: 210
HEAT CAPACITY (W.s)/(Kg.K)	: 1200
THERMAL RESISTIVITY ((m2.C)/W)/m	: 10
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 1.7E12
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 4

RECORD NO. 7

NAME	: FIBREBOARD SHEATHING
DENSITY (Kg/m3)	: 352
HEAT CAPACITY (W.s)/(Kg.K)	: 1300
THERMAL RESISTIVITY ((m2.C)/W)/m	: 16.5
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 20E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 8

NAME	: INNER WALL
DENSITY (Kg/m3)	: 80
HEAT CAPACITY (W.s)/(Kg.K)	: 725
THERMAL RESISTIVITY ((m2.C)/W)/m	: 20
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 3200E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 9

NAME	: INDOOR AIR
DENSITY (Kg/m3)	: 1.21
HEAT CAPACITY (W.s)/(Kg.K)	: 1005
THERMAL RESISTIVITY ((m2.C)/W)/m	: 0
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.7E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 287.055
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 10

NAME	: PLYWOOD(DOUGLAS FIR)
DENSITY (Kg/m3)	: 544
HEAT CAPACITY (W.s)/(Kg.K)	: 1220
THERMAL RESISTIVITY ((m2.C)/W)/m	: 8.7
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 3906E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 11	
NAME	: PARTICLE BOARD
DENSITY (Kg/m3)	: 800
HEAT CAPACITY (W.s)/(Kg.K)	: 1300
THERMAL RESISTIVITY ((m2.C)/W)/m	: 7.4
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 3900E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3
RECORD NO. 12	
NAME	: SEMI-RIGID FIBREGLASS
DENSITY (Kg/m3)	: 100
HEAT CAPACITY (W.s)/(Kg.K)	: 960
THERMAL RESISTIVITY ((m2.C)/W)/m	: 30.5
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.9E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1
RECORD NO. 13	
NAME	: FIBERBOARD SIDING
DENSITY (Kg/m3)	: 800
HEAT CAPACITY (W.s)/(Kg.K)	: 1300
THERMAL RESISTIVITY ((m2.C)/W)/m	: 10.7
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 503E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3
RECORD NO. 14	
NAME	: METAL SIDING
DENSITY (Kg/m3)	: 2740
HEAT CAPACITY (W.s)/(Kg.K)	: 896
THERMAL RESISTIVITY ((m2.C)/W)/m	: .004
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 1E20
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 2
RECORD NO. 15	
NAME	: EXTERIOR AIR FILM
DENSITY (Kg/m3)	: 1.21
HEAT CAPACITY (W.s)/(Kg.K)	: 1005
THERMAL RESISTIVITY ((m2.C)/W)/m	: 15
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.7E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 287.055
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 16

NAME	: WOOD-BASED SIDING
DENSITY (Kg/m3)	: 544
HEAT CAPACITY (W.s)/(Kg.K)	: 1170
THERMAL RESISTIVITY ((m2.C)/W)/m	: 11.9
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 800E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 17

NAME	: GLASS FIBER INSULATION
DENSITY (Kg/m3)	: 25
HEAT CAPACITY (W.s)/(Kg.K)	: 657
THERMAL RESISTIVITY ((m2.C)/W)/m	: 26
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 5.9E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 1

RECORD NO. 18

NAME	: WOOD STUD
DENSITY (Kg/m3)	: 430
HEAT CAPACITY (W.s)/(Kg.K)	: 1200
THERMAL RESISTIVITY ((m2.C)/W)/m	: 9.1
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 800E9
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 3

RECORD NO. 19

NAME	: POLYETHYLENE
DENSITY (Kg/m3)	: 0
HEAT CAPACITY (W.s)/(Kg.K)	: 0
THERMAL RESISTIVITY ((m2.C)/W)/m	: 0
DIFFUSION RESISTIVITY ((Pa.m2.s)/Kg)/m	: 2.1E15
GAS CONSTANT (Pa.m3)/(Kg.K)	: 0
CLASS (1-AIR/2-WATER/3-WOOD/4-OTHER)	: 4